REPORT ON THE CAPSIZE OF THE PASSENGER VESSEL LADY D

FINAL REPORT

26 July 2004

National Transportation Safety Board
Office of Marine Safety
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Washington, DC 20594

Prepared Under Contract GS-23F-0068
Order No. NTSBF040020

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Prepared for:
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Date:
26 July 2004

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Summary of Findings

This report documents the findings of an analysis of the static and dynamic stability of the motor vessel (M/V) LADY D at the time of her capsizing in Baltimore harbor on 6 March 2004. This analysis was performed by John J. McMullen Associates, Inc. under National Transportation Safety Board (NTSB) Order No. NTSBF040020, of Contract No. GS-23F-0068. As stated in the Statement of Work (SOW), this analysis consists of three individual tasks. The first task involved (1) an assessment of the stability calculations for the LADY D and sister vessels performed to show compliance with U.S. Coast Guard passenger vessel stability regulations, and (2) a determination of the adequacy of relevant data to successfully complete a more rigorous analysis of the static and dynamic stability. The second task was to perform a static stability analysis of the LADY D at the time of the capsizing using current USCG regulations. The third task was to evaluate the dynamic effects of wind (steady state and gusting), passenger and crew loading and movement, wave action, and any other relevant conditions, and the interrelationships of these dynamic effects on the stability of the LADY D that may have contributed to her capsizing. The SOW included an optional fourth task, to prepare a 3-5 minute computer animation video, however, at this time this task has not been authorized by NTSB.

Based on the documents provided by NTSB and a survey of the wreckage, it was determined that there was sufficient and accurate data to proceed with the static and dynamic stability analysis of the LADY D. A summary of the significant findings follows:

Evaluation of Existing Stability Calculations and Relevant Documentation

Based on the evaluation of the documentation provided by NTSB, including stability letters for the LADY D and two "sister" vessels, inclining data and calculations performed prior and subsequent to the LADY D capsizing, it is clear that there are a number of factors that point to the vessel having inadequate stability to carry a passenger load of 25 people. Foremost among these factors are the following:

- The LADY D was issued a stability letter based on her "sister" relationship to the RAVEN. RAVEN was granted her stability letter based on her "sister" relationship to the FELLS POINT PRINCESS. That the LADY D was built beyond the 24-month window permitted by Coast Guard for defining a "sister" relationship should be sufficient by itself to question the validity of the stability letter granted by the Coast Guard. However, in this case there a number of significant differences between the LADY D and her "sister" RAVEN that call into question why the a "sister" relationship was considered at all.

- The stability test conducted on the FELLS POINT PRINCESS, upon which both RAVEN and LADY D stability letters were granted, included several errors which made the FELLS POINT PRINCESS look like she had much better stability than she actually did.

Most notable among these errors was misapplication of the stability criteria resulting in a greatly reduced heeling moment used in the calculations.

- There is a question regarding the stability of RAVEN and whether or not a stability test was actually performed on the vessel. The LADY D's stability letter refers to a stability test being performed on RAVEN on 22 November 1992. The Coast Guard reportedly has no record of the test.

- A stability test performed on PATRICIA P (ex-FELLS POINT PRINCESS) on 18 March 2004, following the capsizing of the LADY D, shows the vessel failing to meet the minimum criteria for adequate stability with a test load of only 17 people (passengers plus crew). The results of this test cast into doubt the validity of the original stability test performed in 1992 and upon which both LADY D and RAVEN stability letters were issued.

- There is a significant difference between the average weight of passengers required by the federal regulations (140 pounds per person) and the actual weight of the passengers aboard the LADY D at the time of her capsizing (168.4 pounds per person). This increase in average weight per person equates to a passenger load of 30 at the time of the LADY D's capsizing vice the 25 passengers permitted by her stability letter. The 140-pound average weight per person required by the federal regulations has not changed in decades despite a steady increase in the average weight of the American population.

Had the LADY D undergone a simplified stability test in accordance with the requirements of 46CFR 178.340, it is unlikely the vessel would have passed with a passenger load of 25 people at an average weight of 140 pounds each, let alone 25 people with an average weight of 168.4 pounds. The additional passenger load onboard LADY D reduced the reserve buoyancy available to counter the overturning moments the vessel experienced and was a contributing factor in the vessel's capsizing.

Static Stability Analysis

The static stability analysis performed on the LADY D (Task 2) shows that the vessel does not meet the current regulations of 46CFR 178.340 for pontoon vessels operating in protected waters with the 25 passengers shown on her stability letter issued on March 28, 1996. The analysis showed that the vessel failed to meet the minimum criteria for adequate stability in both transverse and longitudinal directions. Additional calculations were performed assuming a reduced passenger load equivalent to 16 passengers at 140 pounds each as a comparison to the stability test performed on PATRICIA P in March 2004. These calculations again show that the LADY D fails to meet the criteria.

Because the current stability regulations do not address the effects of wind on pontoon boats operating in protected waters, additional calculations were performed to evaluate the theoretical ability of the LADY D to withstand 40-knot beam wind. For these calculations, the vessel was assumed to be loaded as she was at the time of her capsizing, with 25 passengers at 168.8 pounds each. These calculations showed that the vessel possessed sufficient righting energy to resist the 40-knot wind acting on the profile of the vessel. The vessel heeled to about 6 degrees, with slightly less than 2 inches of freeboard remaining, but remained upright. It must be emphasized, however, that these calculations did not consider the dynamic effects of current, wind gusts, waves or the movement of passengers aboard the vessel.

Dynamic Analysis

The dynamic effects of wind and waves acting on the LADY D at the time of the capsizing were sufficient to cause capsize. The condition of 1.25 foot wave chop at a peak period of 3.0 seconds and 25 knot steady wind, gusting to 42 knots, aligned to the port beam showed capsize in 100% of 20 analyzed cases. The average time to capsize was 23.7 seconds. The fastest time was 2.5 seconds. All simulations capsized within 1 minute.

The available weather data, weather observations, photographs and numerical representations of the weather are consistent and are presented with high confidence. Witness observations and photographs were sufficient to estimate ship speed and heading with good confidence. Photographs and records were sufficient to estimate vessel weight and intact dynamic stability with a high degree confidence. Notably:

1. The significant wave height of approximately 1.25 feet used in this analysis is supported by three estimations. As reported in a transcript of witness interviews, Mr. Deppner, captain of the LADY D, observed wave chop of “a foot, foot and a half.” Wave chop of 1 to 1.5 feet can be seen in passenger photograph #3 taken shortly before the capsizing. Theoretical wave development based wind speed and direction measurements taken at the Baltimore Marine Center, approximately 0.25 nautical miles NW of the capsizing site, at the time of the capsizing is estimated to be 1.25 feet.

2. Steady wind speed of 25 knots, with gusts to 41 knots, were recorded at the Baltimore Marine Center (BMC) at 1600:17 EST. Wind speed and gust speed reported at BMC are consistent with the Davenport Wind Spectrum. A standard wind spectrum used in marine vessel and offshore structure designs and analyses. Wind gusts of greater magnitude, beyond those recorded at BMC and modeled by the Davenport Wind Spectrum, such as gusts caused by a wet microburst, were not necessary to instigate capsize.

3. Based on witness testimony and passenger photograph #3, it is reasonable to conclude that LADY D was approximately beam to wind and waves at the time of capsize. It is also reasonable to conclude that wind and waves were co-directional as is expected for a wind generated wave system.

4. This analysis was performed at 5 knots. This speed estimate is supported by the approximate distance traveled, the duration of travel, maximum speed that the LADY D is capable of and speed reduction due to wind and wave resistance.
5. The passenger load, static stability and righting moment of the LADY D were used in the dynamic analysis. Passenger movement, that would alter static stability, was not necessary to instigate capsize.

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1. Introduction

On 6 March 2004 the LADY D, carrying 23 passengers and 2 crewmembers, in route from Fort McHenry to Fells Point, encountered a rapidly developing storm, with high winds, and capsized in Baltimore Harbor. This incident resulted in the deaths of five individuals.

The LADY D is an aluminum pontoon boat 36 ft in length by 8 ft in beam, powered by a single 90 hp outboard motor. The vessel was built in Willow Street, Pennsylvania, and was being operated as a Seaport Taxi, serving the City of Baltimore Inner Harbor area. The vessel carried an undated Stability Letter from the U.S. Coast Guard Officer in Charge, Marine Inspection, Baltimore, MD. The letter certified that the stability of the LADY D was satisfactory for operations, under reasonable conditions, with a maximum capacity of no more than 25 people (passengers plus crew). The vessel also had a Certificate of Inspection from the USCG, dated 28 February 2002, specifying that the vessel carry no more than 25 passengers, "not more than 1,000 feet from shore under reasonable operating conditions."

Capsizing of the LADY D, however, calls into question the applicability of current Federal regulations to vessels of this type and service. NTSB has been charged with the responsibility to investigate the facts surrounding the capsizing of the LADY D, determine the root cause of the capsizing and recommend appropriate regulatory changes to guard against future occurrences.

JJMA was awarded Order No. NTSBF040020, under Contract No. GS-23F-0068, to provide engineering services as part of the investigation into the capsizing of the LADY D. The scope of work includes the following four tasks:

Task 1 - Evaluate and document the USCG Stability assessment for the LADY D, including simplified stability tests, sister vessel designations, inclining experiments, and stability calculations performed to show compliance with the USCG passenger vessel stability requirements.

Task 2 – Evaluate and document the intact stability of the LADY D at the time of the capsizing using generally recognized naval architecture software.

Task 3 – Evaluate and document the dynamic affects of wind (steady state and gusting) passenger and crew loading and movement, wave action, and any other relevant conditions, and the interrelationships of these dynamic affects on the stability of the LADY D that may have contributed to capsizing of the vessel.

Task 4 – Prepare a 3-5 minute computer animation video illustrating the capsizing event, showing the dynamic movements that NTSB determines contributed to the event.

This report documents the results of Tasks 1, 2 and 3. As of this date, Task 4 has not been authorized by NTSB.

2. Data Collected

The data collected as part of this report comes from two sources: (1) that provided to JJMA by the NTSB and (2) data collected directly by JJMA personnel. NTSB supplied data is addressed in Section 2.1. The numbering sequence for NTSB provided data reflects the order in which it was received. Data collected by JJMA personnel is addressed in Section 2.2. The data collected by JJMA was used to verify data received from the NTSB and will be used in follow-on tasks, if authorized.

2.1 NTSB Supplied Data

The following documents were received by JJMA from the NTSB as part of this investigation:

1) Stability Letter (1 page), and Certificate of Inspection (2 pages) for the LADY D. These documents were issued by the U.S.C.G in Baltimore, MD.

2) Stability Letter for the RAVEN (1 page), Fax cover sheet (1 page), and miscellaneous data sheets (13 pages). These documents were sent by the USCG Marine Safety Center, Toledo, Ohio.

3) Stability Letter for the FELLSPOINT PRINCESS (1 page), stability calculations (9 pages), and excerpt from the Marine Safety Manual (2 pages). The stability letter was issued by the USCG in Baltimore, MD.

4) Raw inclining data for the PATRICIA P, and for the LADY D. This document contains miscellaneous dimensional, weight, and tangent data for the two vessels. The document was supplied by the USCG Marine Safety Center, in Washington D.C.

5) Stability test data for the PATRICIA P. This includes a Fax cover sheet (1 page), and stability calculations (7 pages). This document was sent by the USCG, Sector Baltimore.

6) Passenger list, with weights, (1 page) and seating diagram (1 page) for the voyage on which the LADY D capsized. This document was obtained from the NTSB.

7) "H-35 Powering And Load Capacity Of Pontoon Boats" by the American Boat & Yacht Council, Inc. (10 pages).

8) E-mail message from Susquehanna Santee Boatworks, dated May 13, 2004. Subject: LADY D Theoretical (sp) Cabin Weight.

9) CD-ROM with Stability Study Documents dated 2004 May 10. Includes USCG static stability documents and digital photos from LADY D passengers, US Navy landing craft

on the day of the capsizing, NTSB of the damaged vessel, and the USCG simplified stability test of the Patricia P.

10) Digital photos of the MISTY HARBOR II (a sister vessel of the LADY D) were provided by Susquehanna Santee Boatworks. Photos show the interior and exterior of the vessel while resting on a trailer.

Additional data related to weather conditions at the time of the capsizing was provided in a subsequent e-mail from NTSB (Mr. Roth-Roffy) on 17 June 2004.

2.2 JJMA Collected Data

To collect data for construction of the analytical models, a survey of the LADY D wreckage was performed on 11 May 2004 at the Anchor Bay East Marina in Dundalk, MD. The wreckage consisted of two primary pieces: the hull, which included port and starboard pontoons, deck and cross structure, fuel tanks, console, and the engine; and, a large portion of the transverse bulkhead from the aft end of the deckhouse. Present at the time of the survey were: Mr. Tom Roth-Ruffy (NTSB), Captain Ed Narizzano (Seaport Taxi), and Mr. Ric Van Hemmen (Martin, Ottaway, van Hemmen & Dolan, Inc.). The survey started with a visual examination of the vessel while it was suspended in a travel lift as shown in Figure 1. After taking measurements of the vessel in the travel lift, the vessel was placed in the water and measurements of the freeboard were taken.

While the vessel was in the travel lift, damage was noted to the starboard pontoon in the stern and further forward. Captain Narizzano noted that this damage was caused to the LADY D during rescue operations following the capsizing. Water was observed to be coming out of the starboard pontoon at the transom in way of the damage to the pontoon. The pontoons are constructed in sections with transverse bulkheads fitted between sections. The bow and the aftermost compartment are three feet long, and the middle sections are each six feet long. The overall length of the vessel is about 36 feet. An inspection was made of each section of both port and starboard pontoons to determine if there was water in any of the sections. This was done both visually and by tapping the pontoon and listening for a hollow sound. The only section that showed any evidence of water in it was the aftermost section of the starboard pontoon. Water was observed leaking out and it did not sound empty when tapped.

To drain all the water out of the pontoon prior to launching the vessel, a small hole was drilled in the bottom of the pontoon near the transom. The vessel was hanging in the slings of the travel lift with the stern lower than the bow. Water was allowed to drain from the pontoon until the flow stopped. The hole was then plugged with a screw and gasket, and the damaged areas of the pontoon were sealed with epoxy. Once the epoxy had set, the boat was launched and prepared for reading the freeboards. Freeboard readings were taken at the bow, amidships, and stern of the vessel on both port and starboard sides as illustrated in Figure 2. A measurement of freeboard of each pontoon was also taken at the aft end of each pontoon. A summary of the measurements of the vessel can be found in Figure 3.

Figure 1 LADY D on May 11, 2004

Figure 2 Freeboard Reading at Aft End of Port Pontoon

Figure 3 Principal Dimensions of the LADY D

Dimension	Port Pontoon	Starboard Pontoon
Length Overall	36'-0"	35'-11-7/8"
Amidships Pontoon Girth	6'-4"	6'-4"
Calculated Pontoon Diameter	24.2"	24.2"
Amidships Depth (Baseline to Deck)	2'-7-1/8"	2'-7-1/8"
Amidships Freeboard	22-3/8"	23"
Amidships Draft	9-1/4"	9-1/8"
Freeboard at Transom	14-3/4"	14-5/8"
Calculated Draft at Transom	9.45"	9.575"
Overall Beam (rub rail to rub rail)	8'-4"	

Measurements were also taken of the topside of the vessel including the benches, gas tanks, boarding ladder, and the remaining deckhouse bulkheads. The portside passenger bench is intact and attached to the vessel. Captain Narizzano identified the starboard gas tank as being the original tank fitted to the vessel by the builder and the port tank as being an addition made to the vessel after delivery in 2002. The starboard side bench was not attached to the vessel, but pieces of it were available for inspection and measurement. Both port and starboard gas tanks are intact and attached. The forward boarding ladder is attached and intact. The control station is intact and attached to the vessel, although the helmsman's chair is damaged and the seat almost detached from the base. The pieces of the deckhouse bulkhead that remain were identified by Captain Narizzano as being part of the aft bulkhead and the frame of one of the side panels. The aft deckhouse bulkhead remains included the door.

The vessel is powered by a 90-hp Honda gasoline powered, outboard motor. Captain Narizzano stated the vessel was originally delivered with a 36-hp Yanmar diesel outboard engine, but that was replaced by the 90-hp Honda motor at a later date.

3. Assumptions

To be able to successfully complete the analysis described in the SOW, information about the vessel's weight, center of gravity, and wind profile were needed. Since the majority of the deckhouse of the LADY D was missing, assumptions were made about the size and weight of the deckhouse. These were made based on the data from the wreckage survey, the one passenger photo of the LADY D provided in Figure 4, and pictures of the MISTY HARBOR (data item #10) supplied by the boat builder. The deckhouse was constructed of 1.25-inch square aluminum tubing covered with thin (0.019-inch) aluminum sheet metal. Windows were either plate glass or Plexiglas. The survey of the vessel indicated that the deckhouse was 24'-1½" long and 7'-8" wide. It was estimated based on measurements of the partial aft bulkhead and the pictures of the MISTY HARBOR provided in Figure 5 that the height of the deckhouse at the sides is about 7'-0" and in the middle at the peak of the canopy it was 7'-6". The deckhouse has a peaked canopy, not a flat roof. Using the measurements of the vessel and unit weights of materials provided by the boat builder in Data Item #8, JJMA calculated the weight of the deckhouse as 975 pounds. The weight of the missing starboard bench was also calculated using measurements from the JJMA survey and data from the existing portside bench. The weight of the bench was calculated as about 92 pounds. These two pieces of data were be used along with the NTSB supplied passenger weight data, and the weight of the remaining hull to establish the total weight of the vessel at the time of her capsizing.

Figure 4 LADY D on March 6, 2004 Prior to Capsizing

Figure 5 Interior of MISTY HARBOR Deckhouse Showing Canopy Construction

4. Evaluation of USCG Intact Stability Assessment

This section documents the evaluation of the USCG stability assessment of the LADY D including the following:

- Examination of the relationship of the Coast Guard stability letters between the LADY D, and its sister vessels the RAVEN and the FELLS POINT PRINCESS,
- Examination of the stability tests performed on the FELLS POINT PRINCESS and the RAVEN,
- Discussion of the stability criteria that apply to the LADY D,
- Examination of the stability test performed on the PATRICIA P (ex-FELLS POINT PRINCESS),
- Examination of the passenger loading of the LADY D at the time of capsize, and finally
- Conclusions and observations about the stability of the LADY D.

Raw data from the March 2004 inclining of the PATRICIA P and April 2004 inclining of the LADY D are not discussed as the material is incomplete and of little value in its present form.

4.1 Sister Vessel Relationships

The stability letter granted to the LADY D is based on the stability letter of the RAVEN, which is in turn based on the stability letter of the FELLS POINT PRINCESS. The LADY D relied upon its sister vessel relationship with the RAVEN to receive its stability letter. Figure 6 illustrates the heritage of the LADY D stability letter.

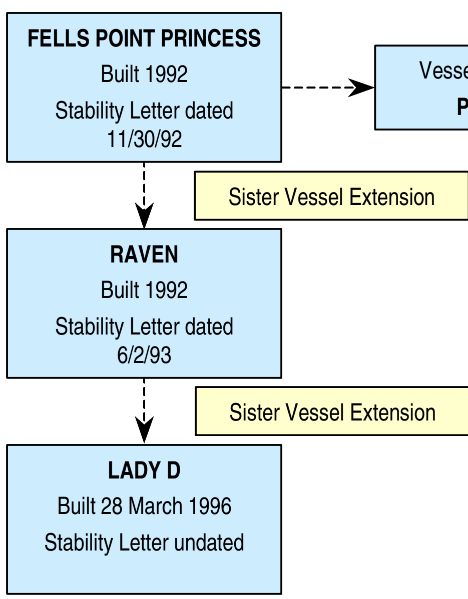


Figure 6 LADY D Stability Letter Heritage

The LADY D Stability Letter, undated, states the following: "The stability of the M/V LADY D has been determined satisfactory based upon its sister ship relationship to the M/V RAVEN, O.N. MD3789C. A simplified stability test for the M/V RAVEN was witnessed and evaluated by the U.S. Coast Guard Marine Safety Office, Baltimore, MD on November 29, 1992."

The RAVEN Stability Letter, dated Jun 2 1993, states the following: "The stability of RAVEN has been determined to be satisfactory based on its sister ship relationship to FELLS POINT PRINCESS, MD7290AN, the stability test on the FELLS POINT PRINCESS conducted at Baltimore, MD on August 12, 1992 and calculations on the subject vessel as presently outfitted and equipped."

The FELLS POINT PRINCESS Stability Letter, dated November 30, 1992, states the following: "A simplified stability test, supervised by the U.S. Coast Guard, was performed on the vessel FELLS POINT PRINCESS on August 12, 1992 at Baltimore, MD. The test was conducted in accordance with the requirements of 46CFR 171.030. Test results indicate that the subject vessel, as presently outfitted, has satisfactory stability for passenger service under reasonable operating conditions for the carriage of not more than 25 persons on protected waters."

The Coast Guard allows the designation of sister vessel status to dispense with the need for a separate stability test when there is data available from the stability test of a sister vessel. NVIC 14-81 provides the basic means for the shipbuilder to attest that two vessels are sisters. The Marine Safety Manual provides some guidelines to help keep the determination of sister vessels as uniform as possible:

- Vessels are constructed in the same shipyard, within approximately 2 years of one another.
- The same basic drawings are used in the construction of both vessels.

The Certificate of Inspection for the LADY D states that the vessel keel was laid on 18 March 1996 and she was delivered on 28 March 1996. The stability letter for the RAVEN is dated 2 June 1993, and the LADY D stability letter references a stability test on the RAVEN of November 22, 1992. This would separate the two vessels construction by at least three years and five months. This falls well outside the guidelines of the Marine Safety Manual for determination of sister vessels between the RAVEN and the LADY D. The RAVEN and the FELLS POINT PRINCESS fall within those guidelines, but the RAVEN and LADY D do not.

4.2 FELLS POINT PRINCESS Stability Analysis

The Stability Letter of the FELLS POINT PRINCESS states a stability test was performed in accordance with 46CFR 171.030. In 1992, when the FELLS POINT PRINCESS was built, 46CFR 171.030 were the only regulations that covered the stability of small passenger vessels. The requirements of 46CFR 171.030 do not specifically address pontoon or multi-hull vessels. The regulations are generic in nature and require calculation of passenger heeling moment and wind heeling moment. Under the greater of those two conditions, the vessel must not exceed the limits of heel that vary according to the type of vessel (i.e. flush deck, cockpit boat, or open boat).

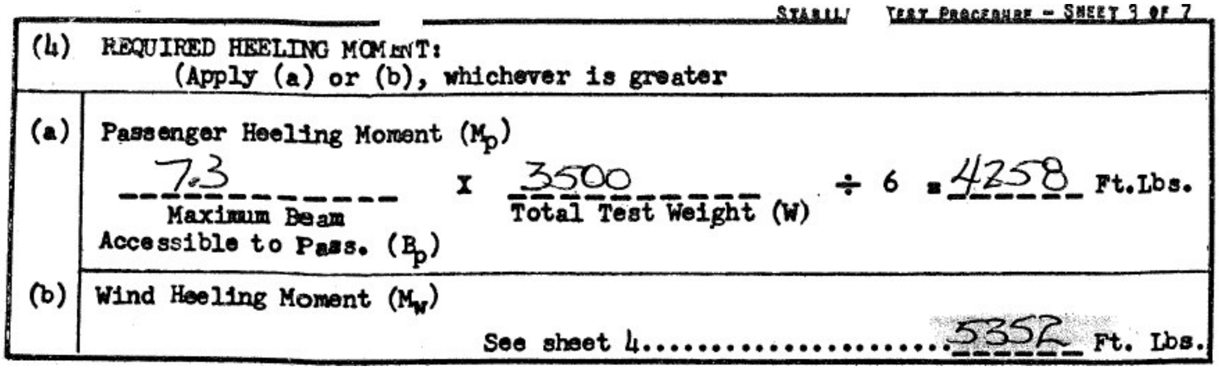
Current stability regulations for pontoon vessels are contained in 46CFR, Part 178, Section 178.340. 46CFR 178.340 replaced existing regulations of 46CFR 171.030 in 1996 with new analysis methodology and criteria, and separate rules for pontoon vessels. The 46CFR 171.030 regulations used a heel angle based criteria for determining acceptable stability, while the new regulations use a reserve buoyancy criteria. The new regulations do not explicitly address wind-heeling moment. The criteria are summarized in Figure 7 below.

Figure 7 Comparison of Stability Criteria in 1992

	46CFR 171.030 (Small passenger vessels)	Marine Safety Manual (Pontoon vessels)
Passenger Heeling Moment	(No. pass. x wt./pass x max. beam) / 6	(No. pass. x wt./pass x max. beam) / 2
Wind Heeling Moment	(Area x height x wind pressure)	None
Transverse Stability Criteria	(1) Maximum allowable freeboard submergence (2) Angle of heel must be less than 14 degrees	Remaining exposed cross sectional area must be equal to or greater than cross sectional area submerged by load shift.

The stability test for the FELLS POINT PRINCESS appears to have been performed in accordance with an early version of the current regulations governing pontoon vessels, which at that time were contained in the Marine Safety Manual, see pages 11 and 12 of Data Package #3. A comparison of the 1992 Marine Safety Manual pages and the current 46CFR 178.340 regulations indicates they are consistent.

There appear to be two basic errors in the FELLS POINT PRINCESS stability analysis. The first error is in the heeling moment used. In the stability calculations it appears that the heeling moment calculations were based on the 46CFR 171.030, while the stability criteria applied was based on that contained in the Marine Safety Manual. The mixing of two separate and distinct criteria, founded on two very different approaches resulted in a significantly reduced heeling moment applied in the stability calculations. On page 4 of Data Package #3 (which shows the calculation based on 46CFR 171.030), the passenger heeling moment was calculated as 4258 ft-lbs, and the wind heeling moment was calculated as 5352 ft-lbs. Heeling moment calculations from page 4 of Data Package #3 are provided in Figure 8.



STABIL/ TEST PROCEDURE – SHEET 3 OF 7

(4) REQUIRED HEELING MOMENT:
(Apply (a) or (b), whichever is greater

(a) Passenger Heeling Moment (M_p)
7.3 x 3500 ÷ 6 = 4258 Ft.Lbs.
Maximum Beam Accessible to Pass. (B_p) — Total Test Weight (W)

(b) Wind Heeling Moment (M_w)
See sheet 4.................... 5352 Ft. Lbs.

Figure 8 Calculation of Heeling Moments for M/V FELLS POINT PRINCES

Applying the criteria from the Marine Safety Manual, as illustrated in Figure 9, the heeling moment that should have been applied is equal to the load (passengers) times the distance to the extreme outboard position, or

3500 lbs x 3.5 ft = 12,250 ft-lbs

This is a very significant difference in heeling moment and has a major impact on the stability calculations.

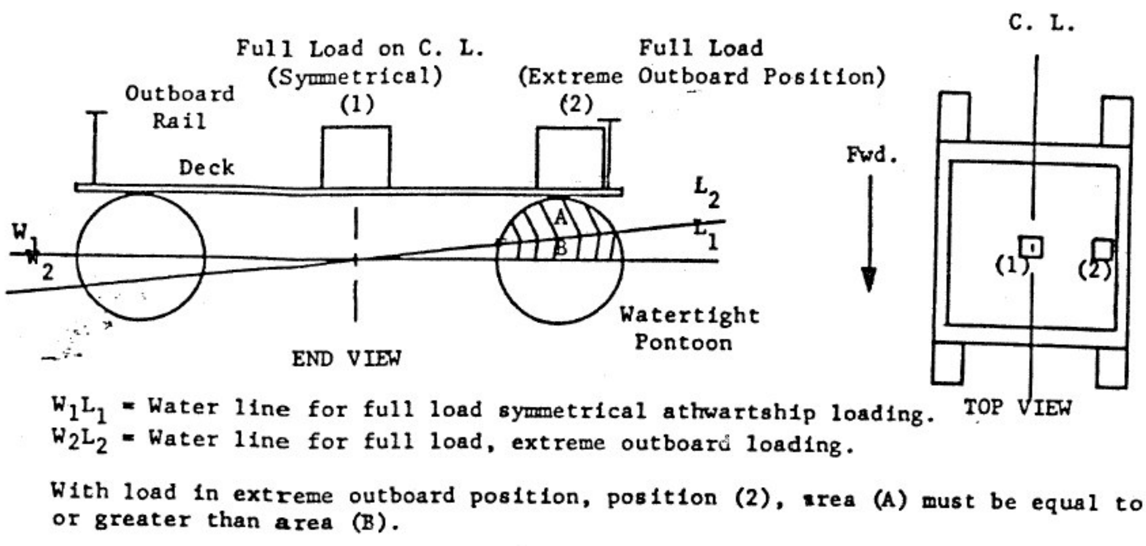
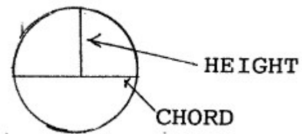


Figure 9 Marine Safety Manual Passenger Heeling moment Calculation

The second error involves the correct diameter of the pontoon hulls. The PATRICIA P (ex-FELLS POINT PRINCESS) has 24-inch diameter pontoons. The calculations on page 9 of Data Package #3, provided in Figure 10, show a chord length of 29 inches in the determination of Area A, and a chord length of 25 inches in the determination of Area B. The chord of a circle cannot be greater than the diameter of a circle. This is either an error in measurement, or the FELLS

POINT PRINCESS had larger pontoons than the LADY D and RAVEN, and should not have been used as the basis for their stability.

STABILITY CALCULATIONS FOR PONTOON VESSELS



H = HEIGHT
C = CHORD
Ref A = MARKS' MECHANICAL ENGINEERS HANDBOOK -
Mathematical tables, Segements of circles given H/C

Area of sections "A & B" = 315.462 at position L1 as determined by the following calculation:

H/C = 14/29 = .482 From column "A" of Ref "A" = .7770

H X C X .7770 = 14 X 29 X .7770 = 315.462 cu. in.

Area of section "A" = 209.19 at position L2 as determined by the following calculation:

H/C = 11/25 = .44 from column "A" of Ref "A" = .7607

H X C X .7607 = 11 X 25 X .7607 = 209.19

Area of Section "B" = 106.272 as dtermined by the following calculation:

315.462 - area of sections A & B
-209.19 - area of section A
106.272 - area of section B

With the load in the 2nd position the area of section A must be equal to or greater than section B.

Figure 10 Calculations of Pontoon Areas

4.3 RAVEN Stability Letter

The RAVEN stability letter dated Jun 2 1993 states that vessel is approved based on its "sister ship" relationship to FELLS POINT PRINCESS, MD7290AN, and the stability test on the FELLS POINT PRINCESS conducted at Baltimore, MD on August 12, 1992". Based on this letter there does not appear to have been a separate stability test performed on the RAVEN. However, the LADY D stability letter specifically mentions, "A simplified stability test for the M/V RAVEN was witnessed and evaluated by the U.S. Coast Guard Marine Safety Office, Baltimore, MD on November 29, 1992." The NTSB has stated that the Coast Guard has no records of any stability test performed on the RAVEN. This draws into question the stability letter of the LADY D.

4.4 LADY D Stability Letter

The LADY D Stability Letter states that the vessel's stability was deemed satisfactory based on its sister vessel relationship with the RAVEN. The Certificate of Inspection for the LADY D states that the vessel keel was laid on 18 March 1996 and she was delivered on 28 March 1996. As previously mentioned, the sister vessel relationship can be questioned between these two vessels since their construction was separated by more than the two years recommended as guidance by the Marine Safety Manual. The LADY D would have been governed by the regulations in the 1995 version of 46CFR since Title 46 is updated annually on October 1.

4.5 PATRICIA P Stability Test

A stability test (Data Package #5) was performed on the PATRICIA P (ex-FELLS POINT PRINCESS) following the capsize of the LADY D on March 18, 2004, using the stability criteria contained in 46CFR 178.340. The PATRICIA P is the sister vessel to the LADY D to which her stability letter is referenced. The stability test data indicates the test weight was calculated for two conditions, including 17 and 25 passengers. A third calculation for 18 passengers, in the margins, is crossed out. It appears that a reduced passenger load (17 passengers) was used for the stability test. The results of the test indicate that the PATRICIA P failed to meet the criteria of 46CFR 178.340. On page 6 of the report, the minimum required arc (27.5 inches) was greater than the measured arc (25 inches) indicating failure to pass the test. The test data also shows that the PATRICIA P has a 24-inch pontoon diameter, the same as the LADY D, and approximately the same length, but has 4 inches less beam. This would make the PATRICIA P inherently less stable than the LADY D with its greater beam.

Because of its smaller beam, using the stability test for the PATRICIA P to draw conclusions on the LADY D is somewhat problematic. That the PATRICIA P appears to have failed the stability test is certainly a warning sign that the stability of similar vessels may not be adequate.

4.6 Passenger Weight Data

Based on the passenger weight data provided by the NTSB (data item #6) the total weight of the passengers onboard the LADY D at the time of the capsizing was 4,209.5 pounds. For the 25 passengers and crew aboard the vessel this works out to an average weight of 168.4 pounds per person. This average weight is significantly greater than the 140 pounds per person used in the simplified stability test. If an average weight of 140 pounds is used, then the LADY D was loaded with the equivalent of 30 passengers at the time of the capsizing. This is far in excess of the revised allowable passenger load calculated for the PATRICIA P based on the simplified stability test performed in March 2004. The additional weight reduced the reserve buoyancy available from the pontoons, thus reducing the vessel's seaworthiness.

4.7 Observations and Issues

The review of the existing stability documentation raises a number of issues about the stability of the LADY D. First there is the issue of sister vessel relationships between the three vessels. The

Coast Guard has guidelines for determination of sister vessel status which include time between construction of the vessels and the use of the same basic plans. In the case of the LADY D this can be called into question on both criteria. The RAVEN was built at least 3 years and 5 months before the LADY D, and the LADY D has a greater beam than the FELLS POINT PRINCESS from which her stability is derived. A difference in beam can have a significant impact on a vessel's transverse stability.

Second, there is the manner in which the FELLS POINT PRINCESS stability test was conducted. The determination of the heeling moments to be used in the tests was done correctly in accordance with the requirements of 46CFR 171.030. Yet the criteria to determine if the vessel had adequate stability was done in accordance with the Marine Safety Manual for pontoon vessels, which are different from those of 46CFR 171.030. Then there are the errors in measuring the chord lengths of the pontoons during the test. The chord lengths were greater than the diameter of the pontoon, which is physically impossible. The combination of the use of the mixed criteria and the measurement errors made the FELLS POINT PRINCESS look like it had better stability that it actually did.

Third, there is the question about the stability of the RAVEN and whether or not a stability test was actually performed on the vessel. The RAVEN stability letter makes no mention of a stability test performed on the RAVEN. However, the LADY D stability letter specifically calls out a test performed on the RAVEN on November 22, 1992. The Coast Guard, reportedly, has no records of the test.

Fourth, there are the questions raised by the PATRICIA P (ex-FELLS POINT PRINCESS) stability test performed on March 18, 2004. This test was performed in accordance with the current rules for pontoon vessels, 46CFR 178.340. This simplified stability test shows the vessel failing with only a test load equal to 17 passengers. The simplified stability test simulates the crowding of passengers to one side of the vessel only and does not have any consideration for the dynamic effects of wind and waves. The test provides a measure of safety by requiring reserve buoyancy that should counter an overturning moment from either off-center passenger loading or wind pressure. The results of the test on the PATRICIA P casts significant doubt on the original stability test performed in 1992 on the FELLS POINT PRINCESS.

Finally, there is the issue of the average weight of a passenger used in determining the stability test load. The CFR calls for weight of 140 pounds per passenger for vessels operating in protected waters. However, at the time of capsize of the LADY D the average passenger weight was 168.4 pounds. This works out to a passenger load of 30 people, at 140 pounds each, on the vessel at time of capsize. This calls into question the adequacy of the average passenger weight required by the regulations. The average passenger weight used in stability calculations has not changed in decades despite of a steady increase in the average weight of the American public.

Clearly there are a number of factors in the stability documentation of the three vessels that point to the LADY D not having adequate stability to carry a passenger load of 25 people. Had the

LADY D undergone a simplified stability test in accordance with the requirements of 46CFR 178.340, it is unlikely the vessel would have passed with a passenger load of 25 people at an average weight of 140 pounds each, let alone 168.4 pounds each. The additional weight of people onboard LADY D reduced the reserve buoyancy available to counter the overturning moments the vessel experienced.

5. Static Stability Analysis of LADY D

The SOW for Task 2 states: "Evaluate and document the intact stability of the LADY D at the time of the capsizing using generally recognized naval architecture software." This section documents the analysis performed to evaluate the intact stability of the LADY D at the time of the capsizing using the General Hydrostatics (GHS) program produced by Creative Systems, Inc. This section describes (1) how the vessel was modeled in GHS, (2) reconstruction of the LADY D's weight and center of gravity, and (3) analysis of the vessel's intact stability against the stability standards for pontoon vessels contained in the current CFR. The stability is analyzed for a number of loading conditions including: (1) the actual load at the time of the capsizing, (2) the rated load according to the vessel's stability letter, and (3) a reduced 16 passenger load that corresponds to the revised stability letter for her sister vessel PATRICIA P (ex-FELLS POINT PRINCESS).

5.1 Modeling of the Vessel.

The vessel pontoons, deck, deckhouse, stairs, fuel tanks, and motor were modeled in GHS for the stability analysis based on the data collected in the vessel survey conducted on 11 May 2004. Each pontoon is 36 feet in overall length. Each pontoon has a 3 foot long tapered bow section that is attached to 33 feet long by 2 feet diameter cylindrical tube. The distance between the centerline of the pontoons is 6 feet 2 inches. The Forward Perpendicular (FP) for the model is assumed to be 3 feet aft of the tip of the bow. The baseline for the model was assumed to be the bottom of the pontoon tube. The small keel piece on each hull (¾ inch square) was assumed to be negligible, and not included in the model. The boarding stairs, fuel tanks and outboard motor were all modeled using measurements taken during the survey of the wreckage.

Modeling the deckhouse was slightly more complicated due to the loss of most of the deckhouse structure. The length and width of the deckhouse were accurately measured during the survey from the remaining footprint. The maximum deckhouse dimensions were 24 feet 1½ inches long and 7 feet 8½ inches wide. A partial height for the deckhouse of 6 feet 5½ inches was measured from the remaining pieces of the aft bulkhead. This height was to the top of the window frame support. Based on photos provided by the vessel's manufacturer of a similar vessel and the passenger photo of the LADY D taken on the day of the capsizing, the overall height of the deckhouse was estimated to be 7 feet at the side and 7 feet 6 inches on centerline at the peak.

All of the calculations for the vessel were done in fresh water. According to research done by physical oceanographers, Bill Boicourt and Peter Olson, the Patapsco River has a three-layered circulation pattern. There is a surface layer of fresh water flowing from the Susquehanna River, a bottom layer of salt water flowing up the bay, and a middle layer of intermediate salinity caused by the mixing of outflow from the Patapsco River and the two in-flows from the Chesapeake Bay (see MD Marine Notes Online, March-April 2001 at:

http://www.mdsg.umd.edu/MarineNotes/Mar-Apr01.

With a draft of less than 2 feet, the LADY D would be floating in the surface fresh water layer. This assumption is further bolstered by salinity measurements in Baltimore Harbor. The MD Department of Natural Resources maintains a water quality monitoring station for Baltimore Harbor on the Patapsco River. Salinity data from the station is available on the Internet at:

http://mddnr.chesapeakebay.net/bay_cond/bay_cond.cfm?Dataion=WT51&Param=sal.

The monitoring station is described as being "tidally influenced mesohaline (salinity 5 to 18 ppt) site" and provides monthly data on surface water salinity. The salinity at the station in March 2004 is reported as 6.60 parts per thousand (ppt). In contrast, seawater has a salinity of 32 to 35 ppt. While the measurement does not show pure freshwater, its salinity is between 15 and 20% that of seawater and the change in the vessel's draft as a result of this slight variation in salinity is less than ⅛ inch. Thus, any variation in the results of the stability analysis due to the slight variation in salinity of the water is negligible.

5.2 Reconstruction of Vessel Weight and Centers

The absence of reliable mass properties data for the LADY D made it necessary to calculate the vessel's weight and center of gravity. As there were no engineering drawings and most of the vessel above the deck was lost in the capsizing, the weight estimate had to be created based upon the remaining wreckage and estimates of the component parts comprising those portions of the vessel that were missing. The weight and center of gravity of the LADY D wreckage was established using the drafts/freeboards taken during the vessel survey. Separate estimates were made for the pontoons, deckhouse, benches, passengers, and other major components using measurements of the vessel, vendor data, photographs, and sister vessel data. The component parts of the vessel were then added together to obtain the weight and center of gravity of the vessel prior to capsizing. The following sub-section summarizes the procedure used, and any critical assumptions made in determining the vessel's weight and center of gravity.

5.2.1 Weight of the LADY D Wreckage

During the survey of the wreckage, freeboard measurements were taken at three locations along the outboard side of both pontoons. Using measurements of the pontoon's diameter, these freeboards were then converted into drafts. Figure 11 shows these measurements and the resulting draft at each station.

Figure 11 Freeboard Measurements and Drafts

Location	Dist. aft of FP (feet)	Keel to Deck (feet)	Keel thickness (feet)	Freeboard (feet)	Draft (feet)
Stbd fwd	-0.03	2.54	0.06	2.08	0.40
Stbd intermed.	17.98	2.59	0.06	1.92	0.61
Stbd aft	29.99	2.58	0.06	1.76	0.76
Port fwd	-0.04	2.54	0.06	1.94	0.54
Port intermed.	17.97	2.59	0.06	1.86	0.67
Port aft	29.98	2.59	0.06	1.76	0.77

The data in Figure 11 shows that there is a difference in the forward draft between the port bow and starboard bow, which indicates some racking between the pontoons. The racking is assumed to have been caused either during the capsizing, the releasing of trapped passengers by the landing craft, or the subsequent righting of the vessel. The model assumes no racking of the hull, i.e., the pontoons are parallel to each other and to the baseline. A check was done to determine the difference between the displacement for the vessel with racking, and with the pontoons square. Figure 12 shows only a very small difference in displacement (38 pounds) and center of gravity between the two conditions.

Figure 12 Vessel Displacement in Racked and Non-Racked Conditions

Displacement for individually trimmed Pontoons					
	Displ. (lbs)	VCB (ft)	VMOM (ft-lbs)	LCB (ft)	LMOM (ft-lbs)
Stbd. Pontoon	1635	0.36	589	18.83	30787
Port Pontoon	1926	0.39	751	17.58	33859
Outboard Motor	7	0.41	3	34.13	229
Total	3568	0.38	1343	18.18	64875
Displacement for both Pontoons using the Mean Trim					
P/S Pontoons	3606	0.38	1370	18.22	65701

5.2.2 Weight of the LADY D Prior to Capsizing

To calculate the weight and centers of the vessel prior to the capsizing, the weight of the wreckage, the actual passenger loading, and estimates of the weight for major components were used. Independent estimates were made for the bare pontoons, passenger load, deckhouse, embarkation stairs, console, captain's chair, battery, fuel tanks, fuel load, Honda outboard motor, life jackets, and port and starboard passenger benches. The weight of the deck, and connecting structure to the hulls, was determined by subtracting individual component weights from the weight of the wreckage. The details of the individual component weight estimates are included in Appendix B. Figure 13 summarizes the weight and center of gravity for the vessel on the day of the capsizing.

Figure 13 Reconstructed Vessel Displacement and Centers

Description	Total Weight (lbs)	VCG (ft above BL)	V Mom. (ft-lbs)	LCG (ft aft of FP)	L Mom (ft-lbs)	TCG (ft, + Port)	T Mom (ft-lbs)
Total weight for 1 pontoon	429.07	1.01	433.20	15.76	6760.04		
Total weight for 1 pontoon	429.07	1.01	433.20	15.76	6760.04		
Deck Structure	1631.23	2.35	3833.39	14.00	22837.19	0.00	0.00
Port Fuel Tank	66.14	3.01	199.15	32.81	2169.86	2.80	185.32
Starboard Fuel Tank	74.97	3.27	245.24	33.05	2477.62	-2.86	-214.72
Debarkation Stairs	97.86	3.82	374.28	1.45	141.55		
Control Console	75.00	4.50	337.50	4.75	356.25	-2.33	-174.75
Captain's Chair	25.00	3.92	98.00	6.25	156.25	-2.33	-58.25
Battery	50.00	2.92	146.00	33.05	1652.50	0.84	42.00
Fuel in Port Tank (@75%)	98.03	2.88	282.62	32.81	3216.07	2.80	
Fuel in Stbd Tank (@75%)	125.57	3.08	386.50	33.05	4149.71	-2.86	
Honda motor (90 hp)	384.00	2.75	1056.00	33.67	12929.28	0.00	0.00
Port Bench	120.06	3.52	422.69	16.04	1925.84	3.15	378.20
Stbd Bench	91.95	3.48	320.15	18.52	1702.89	-3.15	-289.64
Deckhouse	974.71	7.46	7267.24	15.28	14897.09	0.00	0.00
Actual Passengers loading	4209.50	5.07	21340.00	16.56	69703.16	-0.13	-543.33
Lifevests (25)	50.00	3.13	156.50	16.56	828.00	-0.13	-6.50
Total	8932.16	4.18	37331.64	17.09	152663.33	-0.05	-461.26

5.3 Intact Stability Analysis

The intact stability of the vessel has been analyzed using the criteria of *46CFR 178.340, Stability standards for pontoon vessels on protected waters*. These are the statutory requirements that would cover the vessel if she were placed into service today. The LADY D's stability letter indicates she was certified for 25 passengers so the analysis reflects a load equivalent to 25 passengers weighing 140 pounds each. This passenger load is approximately 700 pounds less than the actual passenger load on the day of the capsizing. Calculations were also performed for the actual passenger load on the day of the capsizing and for a reduced passenger load of 16 passengers each weighing 140 pounds. This condition was selected to compare with the results of the Coast Guard stability test performed on the PATRICIA P in March 2004.

Under 46CFR 178.340, the vessel must meet separate stability criteria for an extreme port and starboard movement of the passengers, and for an extreme fore and aft movement of the passengers. For these calculations it was assumed the passenger load was located approximately 8 inches inside the deckhouse for the port/starboard and fore/aft placements. This distance is equivalent to half the width of the passenger bench. The following excerpts from the CFR summarize the applicable criteria.

(c) A pontoon vessel must be in the condition described in Sec. 178.330(a) of this part when the simplified stability proof test is performed, except that the simulated load of passengers, crew, and other weights is initially centered on the vessel so that trim and heel are minimized.

(d) A pontoon vessel has the minimum acceptable level of initial stability if it meets the following:

(1) With the simulated load located at the extreme outboard position of the deck on the side with the least initial freeboard, the remaining exposed cross sectional area of the pontoon on that side must be equal to or greater than the cross sectional area submerged due to the load shift, as indicated in Figure 178.340(d)(1); and

[GRAPHIC OMITTED]

(2) With the simulated load located on the centerline at the extreme fore or aft end of the deck, whichever position is further from the initial position of the load, the top of the pontoon must not be submerged at any location, as indicated in Figure 178.340(d)(2).

[GRAPHIC OMITTED]

5.3.1 Stability Results For 25 CFR Passenger Load

The Stability Letter for the LADY D states: "Based on the above, M/V LADY D is deemed to have satisfactory stability for passenger service under reasonable operating conditions for the carriage of not more than 25 total persons on protected waters". The vessel was checked against the CFR criteria for the centered, and the extreme starboard, port, fore, and aft locations of the passengers. The CFR specifies that the load should be moved to the side with the least initial freeboard. This is the starboard side of the LADY D. Both the starboard and port sides were analyzed for comparison. The load conditions for the vessel in each of these five conditions are shown in Figure 14. The first load condition is the initial load specified in the CFR and is for the passengers centered on the deck. This condition has a draft of 1.08 feet at the origin (FP), and the vessel has a slight starboard heel, and aft trim.

Figure 14 Summary of Load Conditions for 25 CFR Passengers

Passenger Load Position	Total Weight (lbs)	VCG (ft)	LCG aft FP (ft)	TCG (ft)
Centered	8222	4.07	16.50	0.02 s
Extreme Starboard	8222	4.07	16.50	1.36 s
Extreme Port	8222	4.07	16.50	1.32 p
Extreme Forward	8222	4.07	11.65	0.02 s
Extreme Aft	8222	4.07	21.35	0.02 s

Note: Total weight is defined as the weight of the vessel (including fuel) plus 25 passengers at an average weight of 140 lbs each, per 46CFR 178.340.

The results of the stability analysis are summarized in Figure 15. What this figure shows is that the LADY D does not satisfy the minimum stability criteria in any of the four tested conditions. In both the extreme starboard and extreme port load conditions the vessels capsizes. Column 4 of Figure 15 shows the final equilibrium heel angle for the vessel in all loading conditions. For both extreme starboard and extreme port loading conditions the vessels heels to about 165 degrees, which is upside down. The 46 CFR 178.340 criteria are irrelevant in these cases since the vessel has rolled over. The CFR requirements in the extreme forward and extreme aft loading conditions are that the top of the pontoon may not be submerged at any location. For the LADY D in both the cases some point of at least one pontoon is submerged. Column 6 of Figure 15 shows the minimum freeboard in each loading condition. A negative freeboard means the top of the pontoon is submerged. In both these loading conditions, the tops of both pontoons were submerged which violates the stability criteria of the CFR. The GHS output for these load conditions are provided in Appendix C.

Figure 15 Stability Results for 25 CFR Passenger Load

Passenger Load Position	Total Weight (lbs)	Draft @ FP (ft)	Equiv. Heel (degrees)	Trim (ft)	Minimum Freeboard	Pontoon Top Submerged
Centered	8222	1.08	0.17 s	0.20 aft	0.71	No
Extreme Starboard	8222	-1.85	164.72 s	0.08 aft	Rolled over	Yes
Extreme Port	8222	-1.84	164.79 p	0.08 aft	Rolled over	Yes
Extreme Forward	8222	1.94	0.21 s	1.54 fwd	-0.09	Yes
Extreme Aft	8222	0.10	0.37 s	2.44 aft	-0.55	Yes

Based on this analysis it is reasonable to conclude that the LADY D did not possess adequate reserve buoyancy to allow the vessel to safety operate with a 25 passenger load even on protected waters. A simplified stability test, performed in accordance with the 46 CFR 178.340, would have shown the vessel's lack of adequate static stability to carry 25 passengers.

5.3.2 Stability Analysis for Actual Passenger Load

The stability analysis was repeated using the actual passenger load on the day of the capsizing. The actual passenger load was 709.5 pounds heavier than the passenger load used in the previous analysis (see Section 5.3.1 above). As noted elsewhere in this report, the average passenger weight on the day of the capsizing was 168.4 pounds, which is significantly heavier than the weight used in the Coast Guard simplified stability test procedure. It is the equivalent of loading the vessel with approximately 30 CFR passengers (at 140 pounds each). The results of this analysis are predictably similar to the previous analysis. The vessel failed in all loading conditions and rolled over for passengers in the extreme port and extreme starboard positions. The results are not summarized in this report, but the GHS outputs are included in Appendix C.

The righting arm curve for the vessel with the actual passenger loading is shown in Figure 16. The maximum righting arm for the vessel is approximately 0.73 feet and occurs at 11.3 degrees heel.

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GHS 9.00A General HydroStatics

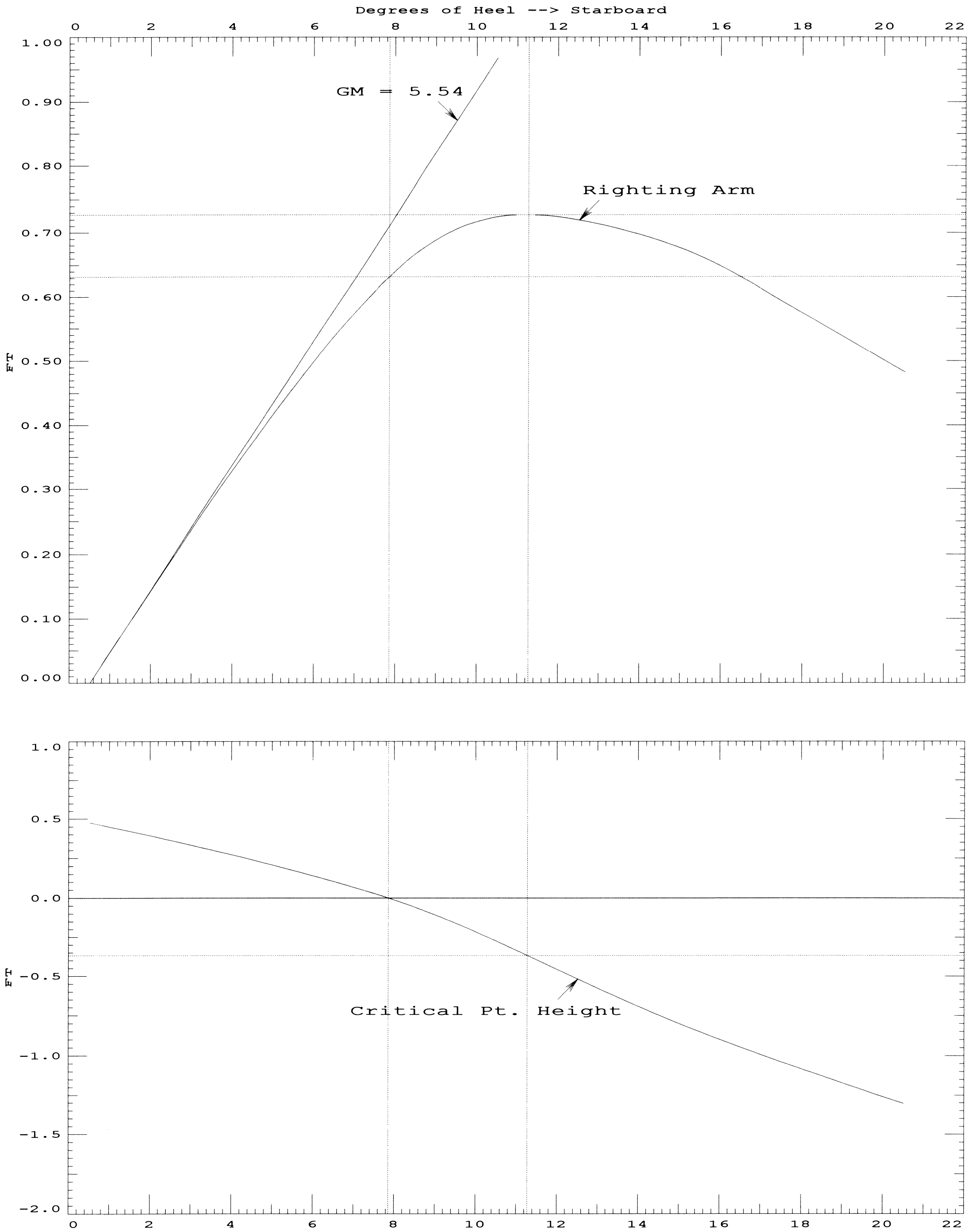

Figure 16 Righting Arm Curve for LADY D

5.3.3 Stability Analysis for 16 CFR Passenger Load

An additional analysis was done to determine if the vessel with a load of only 16 passengers, weighing 140 pounds each, could meet the stability requirements. This is the load the PATRICIA P has been certified for following her simplified stability test in March 2004 following the LADY D capsizing. The vessel was checked against the criteria of 46CFR, 178.340 for the centered, and the extreme starboard, port, fore, and aft locations of the 16 passengers. The loading conditions for the vessel are shown in Figure 17.

Figure 17 Loading Condition Summary for 16 CFR Passengers

Passenger Load Position	Weight (lbs)	VCG (ft)	LCG aft FP (ft)	TCG (ft)
Centered	6962	3.91	16.76	0.02 s
Extreme Starboard	6962	3.91	16.76	1.03 s
Extreme Port	6962	3.91	16.76	0.99 p
Extreme Forward	6962	3.91	13.10	0.02 s
Extreme Aft	6962	3.91	20.43	0.02 s

Note: Total weight is defined as the weight of the vessel (including fuel) plus 16 passengers at an average weight of 140 lbs each, per 46CFR 178.340.

The results of the intact stability analysis are shown in Figure 18. As before, the criteria for the starboard and port load cases is that: “the remaining exposed cross sectional area of the pontoon on that side must be equal to or greater than the cross sectional area submerged due to the load shift”. This means that no more that half the initial exposed cross sectional area can be submerged due to the load shift. Column 5 of Figure 18 shows the “exposed” cross sectional area of the pontoon(s) for the centered load, and for the pontoon on the same side of the load shift for the extreme starboard and port loads. If the number in the “Exposed Area” column of Figure 18 is greater than the number in the “Required Area” column the vessel passes the criteria. As can be seen for both extreme starboard and extreme port conditions the vessel fails to satisfy the minimum criteria for adequate stability.

Figure 18 Results for 16 CFR Passenger Load

Passenger Load Position	Weight (lbs)	Draft @ FP (ft)	Equiv. Heel (degrees)	Exposed Area	Required Area	Pontoon Top Submerged
Centered	6962	0.92	0.13 s	1.26s/1.29p	n/a	No
Extreme Starboard	6962	0.91	6.98 s	0.55	0.63	No
Extreme Port	6962	0.91	6.69 p	0.58	0.65	No
Extreme Forward	6962	1.41	0.13 s	n/a	n/a	No
Extreme Aft	6962	0.40	0.15 s	n/a	n/a	No

Note: n/a – indicates that the requirement is not applicable to the particular condition.

Further, the criterion for the forward and aft load cases is that: “the top of the pontoon must not be submerged at any location”. For the extreme forward load condition, the starboard pontoon has 0.51 feet of freeboard at the forward tip (at the top) of the pontoon. For the extreme aft load condition, the starboard pontoon has 0.27 feet of freeboard at the aft end (at the top) of the pontoon. Therefore, the vessel meets the stability requirements of 46CFR 178.340 for fore and aft loading.

Based on this analysis, it is reasonable to conclude that 15 CFR passengers was the maximum number the LADY D could safely carry and still satisfy the stability criteria of 46CFR 178.340, though this should be borne out by further calculations. It is important to note that there are some differences between the LADY D and PATRICIA P that may contribute to the LADY D's failure to meet the stability criteria with 16 Passengers. Most significant among these differences are:

- The LADY D is about 6-inches wider than her sister vessel. This means she has a wider, and therefore, heavier cross structure.
- The deckhouse on the PATRICIA P is significantly different from the LADY D. The LADY D's deckhouse is enclosed whereas the PATRICIA P's is open.
- The PATRICIA P has no windows on the sides or rear of the vessel, and she does not have either a front or rear door. These items alone on the LADY D are estimated to weigh 445 pounds alone.
- The overall height of the deckhouse on the PATRICIA P is also lower by at least six inches.

All these differences add up to around 500 pounds, which is equivalent to about 3.5 extra passengers, or about 7% of the vessel's displacement. While the LADY D does have 6 inches greater beam than the PATRICIA P, this by itself is insufficient to compensate for the differences identified.

5.4 Effect of Wind on Static Stability

46CFR 178.340 does not address wind as a stability criteria for pontoon vessels operating on protected waters. There is the presumption that these vessels would be sheltered from the effects of wind or would not be operating in high winds. Yet wind appears to have been a significant factor in the LADY D capsize. Therefore the effect of wind on the intact stability of the LADY D was analyzed using GHS. This analysis was purely static and did not consider dynamic factors such as waves, passenger movement, etc. A heeling moment was calculated for a 40-knot beam wind using the vessel profile and applied to the vessel in the actual loading condition. The vessel was assumed to be floating in calm waters. The resulting righting arm curve for the vessel is shown in Figure 19. This figure shows that the vessel would be heeled over to approximately 6-degrees by a 40-knot wind, but would not capsize due to wind force alone. There is still a small amount of residual righting energy (area under the curve) to counteract overturning forces, but it is very small. The maximum righting arm is only about 0.26 feet (3-inches). Comparing this curve to the righting arm curve for the vessel shown in Figure 16, it can be seen that more than half of the righting energy has been lost due to the effects of the wind. This leaves the vessel with very little margin to resist additional overturning forces.

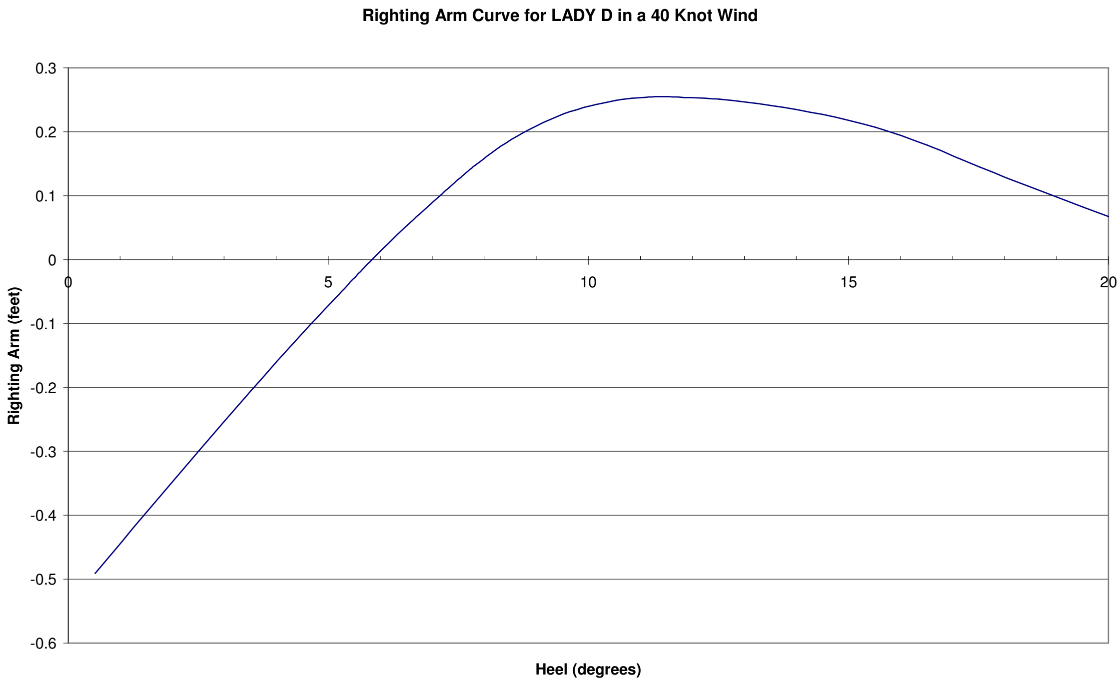

Figure 19 Residual Righting Arm Curve for 40-knot Wind

6. Dynamic Stability Analysis of LADY D

Using generally recognized naval architecture software and analysis methods, the dynamic effects of wind and waves acting in combination on the LADY D were evaluated. The analysis is predicated on factual data and best estimates of these 3 parameters:

1. Hull – geometry and mass properties
2. Environment – wind and waves
3. Ship Control – heading and speed

First JJMA developed best estimates of those 3 parameters. Then accurate simulation models and numerical representations, necessary for inclusion in the dynamic simulation, were generated. Then dynamic simulations using the frequency and time domain simulation program AQWA were conducted. The motions of the LADY D due to wind and waves generated from the dynamic simulations were analyzed. In other words, AQWA simulations incorporating the 3 parameters were executed 20 times with perturbations in the initial conditions. The resulting output of the 20 simulations were analyzed to determine probability of capsize, duration of exposure to wind and waves prior to capsize, and other statistics.

Presentation of the method of determining the 3 parameters, how the AQWA simulation works and the dynamic analysis follow.

6.1 Data Collected

Three key pieces of information were provided by NTSB. These were (1) local wind data at the time of the capsize, (2) a photograph of the wave field immediately prior to the capsize, and (3) the series of events aboard the LADY D prior to the capsizing developed via witness interviews. The NTSB provided data is presented in this report section. Analysis, interpretation and implementation of the data is presented in report Section 6.3.

The weather specialist at NTSB, Gregg Salotollo, provided wind condition records. Data from four nearby measuring stations were available. The stations and their distance from the capsizing site are:

- Baltimore Marine Center approximately 0.25 nautical miles northwest
- Baltimore Shock Trauma Center approximately 2.7 nautical miles west-northwest
- FAA Airport Wind TDWR approximately 8 nautical miles southwest
- Baltimore Washington International Airport approximately 6.6 nautical miles southwest

The station locations are shown in Figure 20

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Figure 20 Nautical Chart of Baltimore Harbor and surrounding area

The largest steady wind speeds, gusts and their directions in degrees true at each station between the times of 1550 and 1600 March 6, 2004 were:

1600:17 EST Winds 299° at 25 knots gusts to 41 knots
(Baltimore Marine Center - elevation about 10 feet)
1556:48 EST Winds 289° at 33 knots gusts to 49 knots
(Baltimore Shock Trauma Center - elevation about 181 feet)
1559:07 EST Winds 299° at 27 knots gusts to 45 knots
(Airport Wind TDWR Data from FAA - elevation about 144 feet)
1557 EST Winds 290° at 41 knots
(Surface Weather Observation from Baltimore Washington International Airport - elevation about 144 feet).

The largest winds at each station are of little interest to this analysis except as verification that all nearby stations showed high wind and gust activity from nearly the same direction. But of primary interest are the weather observations at nearby Baltimore Marine Center (BMC). Wind observations at BMC were:

1550 EST Winds 285° at 8 knots gusts to 14 knots
1552 EST Winds 287° at 12 knots gusts to 16 knots
1554 EST Winds 271° at 14 knots gusts to 18 knots
1556 EST Winds 273° at 11 knots gusts to 18 knots
1557 EST Winds 294° at 13 knots gusts to 23 knots
1558 EST Winds 307° at 16 knots gusts to 23 knots
1559 EST Winds 301° at 21 knots gusts to 37 knots
1600 EST Winds 299° at 25 knots gusts to 37 knots

Maximum individual gust observations at BMC show an increasing trend:

1551:38 EST 16 knot gust
1552:29 EST 18 knot gust
1556:57 EST 23 knot gust
1558:07 EST 28 knot gust
1558:47 EST 32 knot gust
1558:58 EST 37 knot gust
1600:17 EST 41 knot gust

Passenger photograph #3 taken shortly before capsize is shown in Figure 21. The location of the LADY D where photograph #3 was taken, approximated by NTSB, is shown as labeled as point 2 on Figure 20. The direction of the photograph is also shown. Photograph #3 was used, along with other information, to estimate wave height, wave period, wave direction, ship heading and ship location at the time of the capsizing.

Figure 21 Passenger Photo #3

NTSB provided eyewitness and passenger accounts of the events that preceded the capsizing. These included observations of vessel position, vessel speed, vessel heading, wind speed, wave height, vessel roll angle, passenger movement and helm commands. The witness testimony transcript that NTSB provided is included in Appendix D.

6.2 Assumptions and Simplifications

To facilitate the simulation and dynamic analysis the following were assumed:

- Vessel heel during a turn was not considered.
- Passenger movement was not considered.
- The vessel travels in one direction.

Heel is a non-oscillatory rotation to port or starboard. Estimation of heel during a turn is very complex. When a vessel turns it generally heels away from the turn, i.e. a vessel turning to port will heel to starboard. Ignorance of vessel heel on the LADY D results in a conservative analysis, since, LADY D capsized to starboard during a turn to port. The turn to port would have produced a heel to starboard, in the direction of the capsizing, contributing to destabilization. Therefore, ignoring the destabilizing effect of vessel heel during a turn is a conservative simplification.

Passenger movement prior to and during capsize is not well defined, so it was not included in the dynamic analysis. Passenger movement, the simple act of standing, is destabilizing. Therefore, ignoring the destabilizing effect of passenger movement is a conservative simplification.

The vessel was simulated traveling in one direction. It was not turning during the simulation. The reason for this is that capsize is a transient event. It happens quickly under specific circumstances. In order to capture those circumstances, the simulation exposes the Lady D to the dynamic conditions (wind and waves) for a longer period than would happen at the instant of capsize during a turn. By traveling in one direction, the direction of dynamic is constant relative to the direction of travel. This simplification is not conservative, but is necessary to facilitate the dynamic analysis.

6.3 Generation of Modeling Parameters

Generation of the components and parameters of the simulation models and conditions follow this hierarchy:

1. LADY D Model
   a. Geometry - hull form and superstructure dimensions
   b. Mass Properties - weight, weight distribution and inertia

2. Environment Model
   a. Wind - steady speed, gust speed and direction
   b. Waves - height, period and direction

3. Ship Control Model
   a. Ship heading
   b. Ship speed

6.3.1 LADY D Model

The LADY D Model is composed of two basic components; the geometry and the mass properties. The model geometry was derived from sketches and an on-site survey of the vessel wreckage. The details and dimensions of the hulls, deck, superstructure and other features have been reported in Section 2.2 of this report. From this information a 3D panelized model, illustrated in Figure 22, was prepared for the simulation.

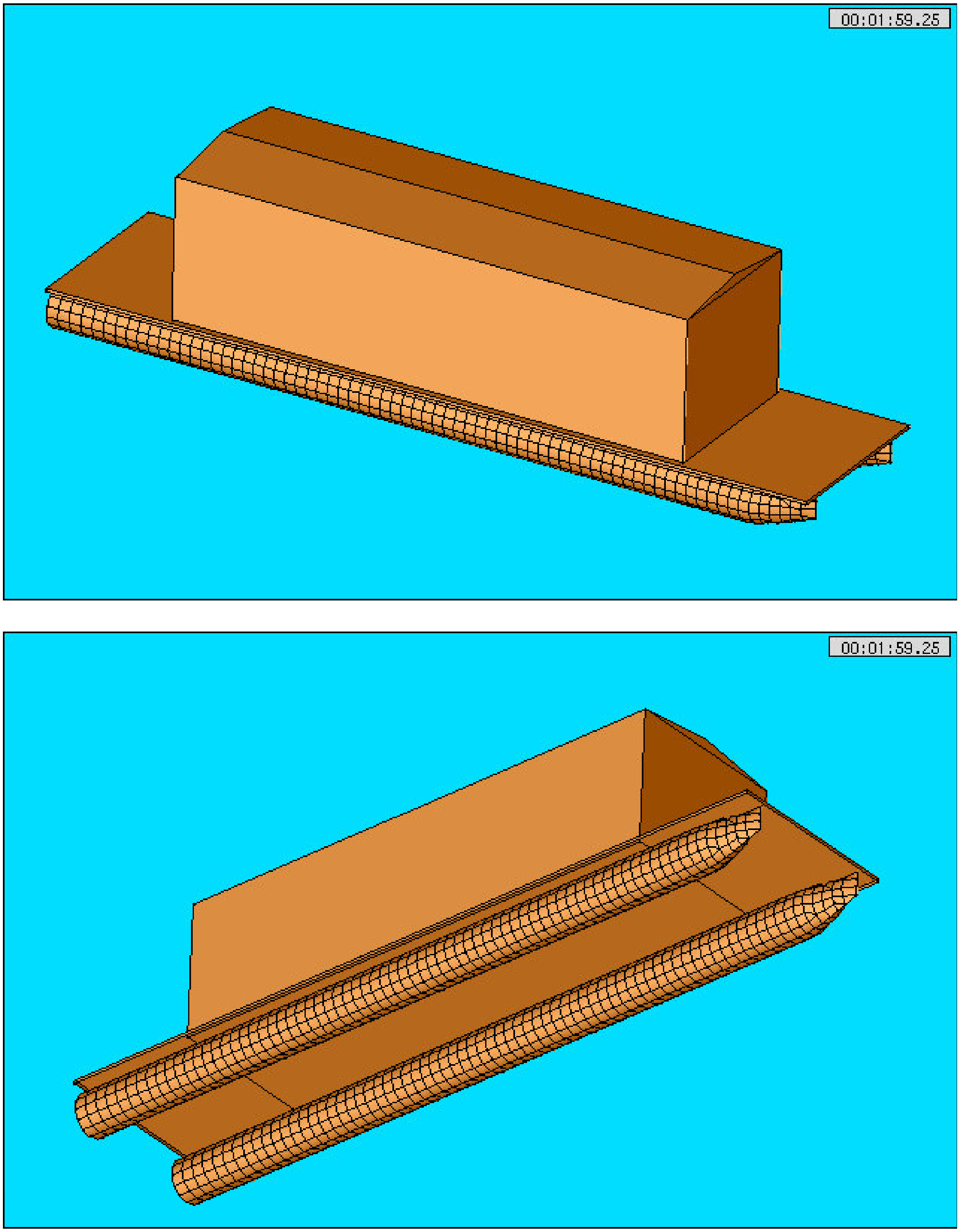

Figure 22 LADY D Panelized Geometry Model

The detailed weights and mass properties were presented in Section 5.2 of this report. A brief summary is shown in Figure 23. Stationary passengers and crew are included in the mass properties. Also, the natural roll period of the Lady D is approximately 2.4 seconds.

Mass, lbs.	Ixx, lbs-ft^2	Iyy, lbs-ft^2	Izz, lbs-ft^2
8,932	92,277	678,981	700,632
Draft, ft	XCG, ft	YCG, ft	ZCG, ft
1.28	17.1	-.09	3.86

Figure 23 Mass Properties Summary

6.4 Environment Model

The environment model is comprised of wind and waves. The characteristics were estimated from actual measurements, witnesses, photographs and theory.

6.4.1 Wind

As discussed above, NTSB provided wind data from four sites, Baltimore Marine Center, Baltimore Shock Trauma and two measurements around Baltimore Washington Airport. Since factual wind data from several measurement sites were available, the wind characteristics were developed first and will be used in the wave system estimation to follow.

Maximum winds in the area reported at the four sites showed general agreement. Between 1555 and 1600 EST winds were generally westerly between 270° and 310° true at about 27 knots steady with gusts approximately 45 knots. The Baltimore Marine Center (BMC) readings were taken at 10 feet above sea level. The remaining 3 sites are elevated well over 100 feet. BMC is approximately 0.25 nautical miles from the capsizing site and located in the northwest harbor. The Baltimore Shock Trauma Center is 2.7 nautical miles away and the airport measurements were 7 to 8 nautical miles away. Based on the elevation and proximity of BMC to the capsizing site, detailed wind condition information from BMC was used for the analysis.

Steady wind speed, gust speed and wind direction reported at BMC are shown in Figure 24. At the time of the capsizing, 1600 EST, winds were 25 knots with gusts to 41 knots from 300° true.

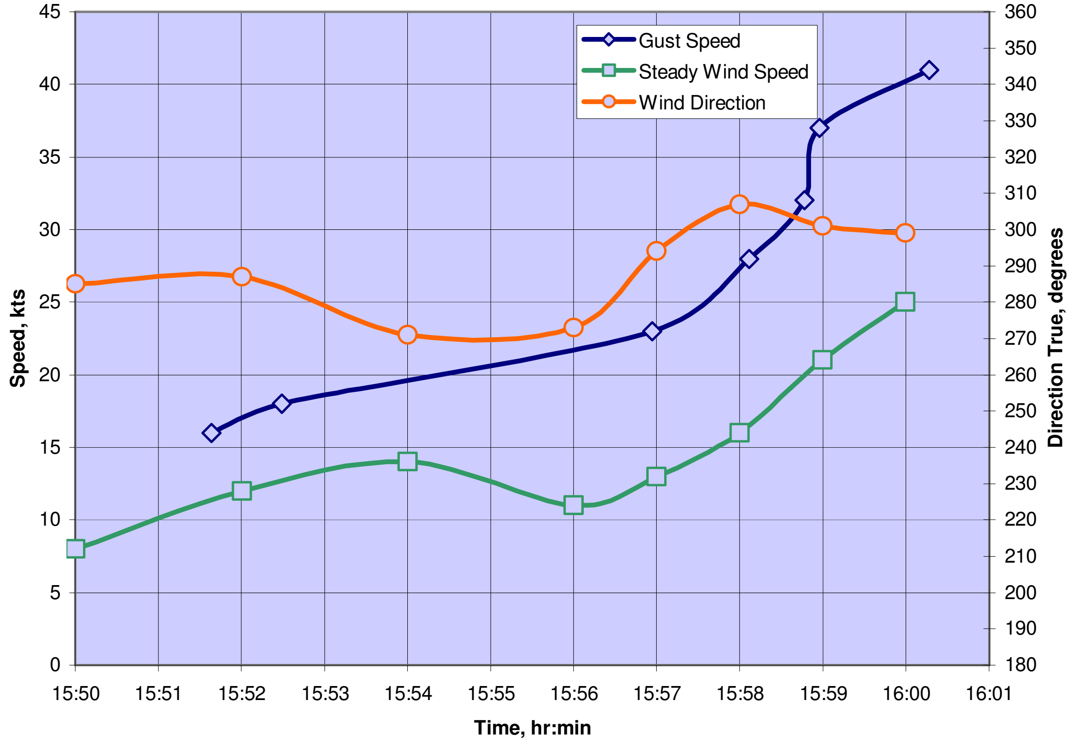

Figure 24 Wind Conditions at BMC March 6, 2004

In order to perform the simulations for the dynamic analysis, the steady wind speed and gust speed had to be converted into a time series. The time series represents the wind speed at any given time and tells the simulation what the wind speed is at each time step as the simulation progresses. A sample of the wind speed time series used in the simulations is shown in Figure 25.

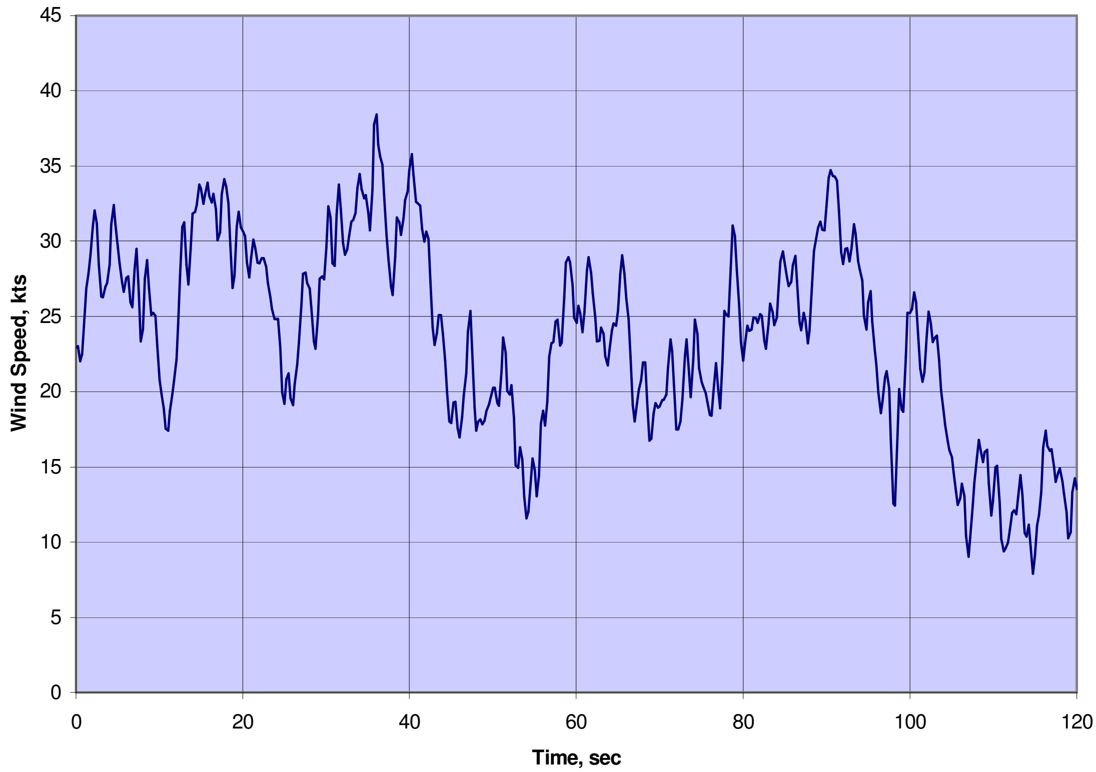

Figure 25 Sample Wind Speed Time Series

In order to generate the time series, an assumption of the spectral representation of wind conditions was necessary. A standard wind spectrum used in general engineering including ship design and offshore marine structure design is the Davenport Gust Spectrum. The variables of the spectrum are mean wind speed and surface drag coefficient. The equations for the Davenport Gust Spectrum are:

$$X = \frac{4000 \cdot \omega}{2\pi \cdot V_{wind}}$$

$$S(\omega) = 4.0 \cdot C_D \frac{{V_{wind}}^2}{\omega} \frac{X^2}{(1 + X^2)^{4/3}}$$

Where: V_{wind} is the mean wind speed in ft/sec,
S is wind energy in (ft/sec)^2-sec,
ω is frequency in rad/sec, and
C_D = 0.005 for water
= 0.020 for trees and low houses
= 0.050 for urban areas with tall buildings (90ft).

In our case, the mean wind speed, V_{wind}, measured at BMC at 1600 EST is 42.2 ft/sec (25 knots) and C_D = 0.02 is most appropriate for Northwest Harbor, a waterway with surrounding buildings. C_D = 0.005 is used for large expanses of open water and C_D = 0.05 is used to calculate gusts between buildings on city streets. The resulting gust spectrum is shown in Figure 26.

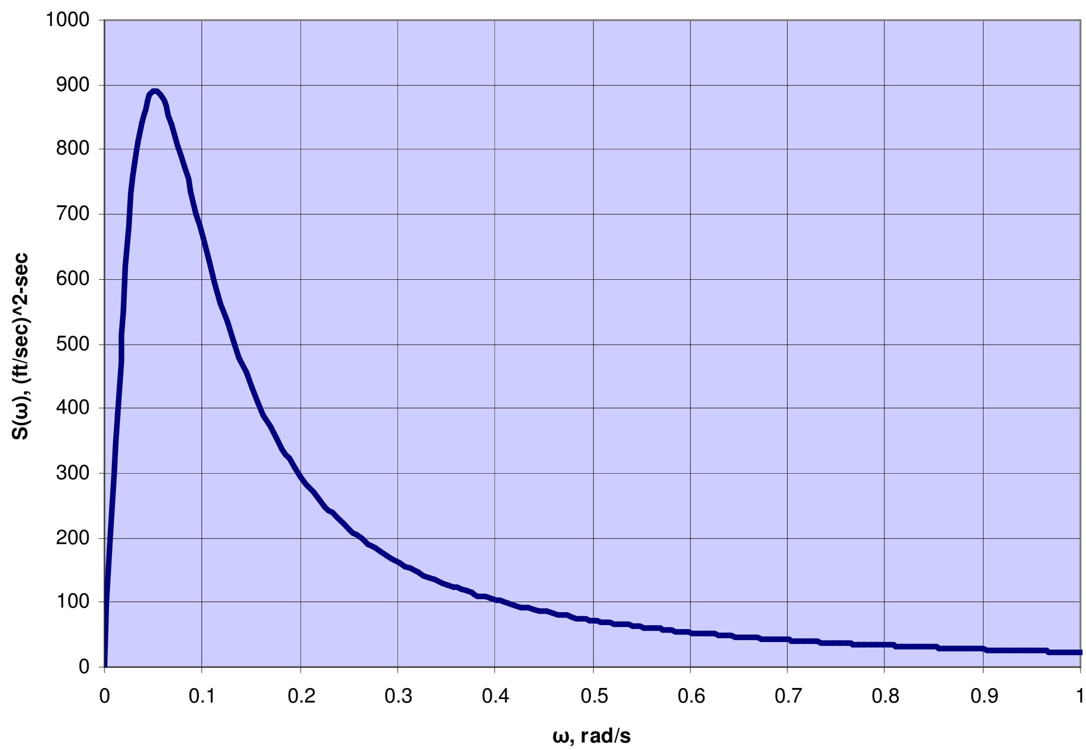

Figure 26 Davenport Gust Spectrum Estimate at Capsizing Site at 1600 EST

The spectrum was converted into a time series by the common method of cosine series representation.

$$V_{gust} = \sum_{\omega=0}^{\omega=\infty} A_\omega \cos(\omega t + \phi)$$

Where: V_{gust} is the wind gust speed above mean wind speed at time t in ft/sec,
ω is frequency in rad/sec,
A_ω is wind energy spectrum amplitude at ω in $(ft/sec)^2$-sec,
t is time in seconds, and
ϕ is a random phase angle.

To make sure that this Davenport Gust Spectrum is representative of the conditions, the significant gust speed is calculated:

$$M_o = \int_{-\infty}^{\infty} S(\omega)$$

$$2\sigma = 2 \cdot \sqrt{M_o}$$

$$V_{gust\ total} = V_{wind} + 2\sigma$$

Where: $V_{gust\ total}$ is the gust speed in ft/s,
M_o is the 0^{th} moment of the spectra, and
σ is the standard deviation.

The result of this calculation shows significant gust activity of 42 knots. Noting that some individual gust peaks will be higher or lower, this compares well with the 41-knot gusts reported at BMC.

Witness observations of wind speed and gustiness were not used. These are generally unreliable. JJMA points out that passengers and crew were inside LADY D.

Since JJMA does not have any factual data indicating a wet microburst, none was assumed. The BMC observations represented as the Davenport Gust Spectrum are used. They are not altered to represent higher magnitude gusts that would accompany a microburst.

Bottom line: the simulations and dynamic analysis use steady wind speed of 25 knots with gusts to 42 knots from 299° true represented by the Davenport Wind Spectrum.

6.4.2 Waves

Three information sources were examined when estimating the wave height, period and direction. These are Photograph #3, Figure 21,witness interviews and theory. The significant wave height of approximately 1.25 feet with a 3.0 second period and JONSWAP wave spectrum used in this analysis is supported by those three estimations. The estimate of wave direction from approximately 300° true, co-directional with wind, is supported. A detailed discussion follows.

NTSB provided a photograph of the seas taken from within the LADY D immediately prior to the capsizing. The photograph, designated Photograph #3, was shown above in Figure 21. From this, JJMA estimates the waves to be choppy at about 1 to 1.5 feet with a short period and narrow spectrum. Narrow spectrum describes a short peaky wave rather than a long rolling wave. Witnesses reportedly observed chop of 1 to 1.5 feet. And a theoretical wind generated wave development estimates significant wave height to be 1.25 feet with 3.0-second period.

In order to perform the simulations for the dynamic analysis, the estimated wave condition had to be converted into a time series. The time series represents the wave speed at any given time and tells the simulation what the height is at each time step as the simulation progresses. Part of a time series used in the simulations is shown in Figure 27.

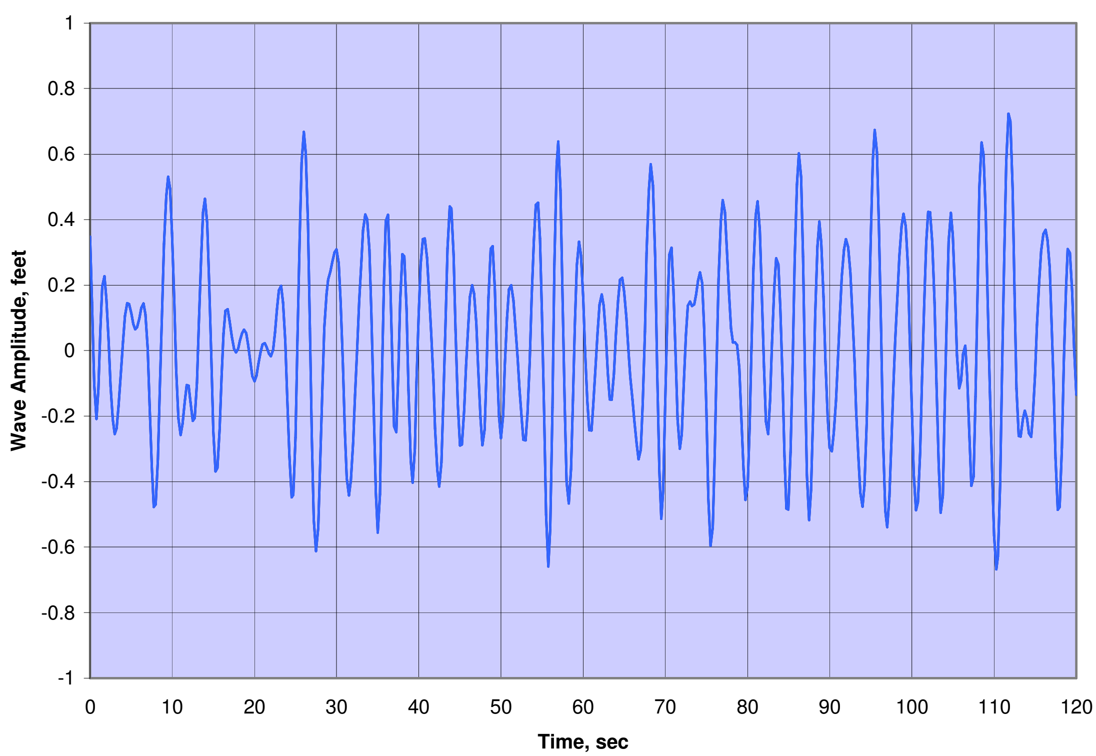

Figure 27 Sample Wave Amplitude Time Series

In order to generate the time series, an assumption of the spectral representation of wave conditions was necessary. A standard wave spectrum used in near shore or littoral waters is the

JONSWAP Wave Spectrum. The variables of the spectrum are mean wind speed and surface drag coefficient. The JONSWAP was developed by The Joint North Sea Wave Observation Project as a representation of seas, which are not fully developed. The wave height is dependent on the steady wind speed and uninterrupted length of water over which the wind blows, called fetch. With fetch and steady wind speed input, the JONSWAP equation gives a two-parameter standard spectral representation of littoral wave systems. The equations for the JONSWAP Wave Spectrum are:

$$\alpha = 0.076\left(\frac{U^2}{x \cdot g}\right)^{0.22}$$

$$\omega_p = 22\left(\frac{g^2}{U \cdot x}\right)^{1/3}$$

$$r = \exp\left[-\frac{(\omega - \omega_p)^2}{2\sigma^2\omega_p^2}\right]$$

$$\sigma = \begin{cases} 0.07; \omega \le \omega_p \\ 0.09; \omega > \omega_p \end{cases}$$

$$S(\omega) = \frac{\alpha \cdot g^2}{\omega^5}\exp\left[-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^4\right] \cdot \gamma^r$$

Where: U is steady wind speed,
x is fetch,
g is gravity,
S is wave energy,
ω is frequency,
ω_p is the peak frequency, and
γ is a shape factor of 3.3.

So in order to develop the theoretical JONSWAP for the conditions at the time of the capsizing, fetch and steady wind speed must be known. As previously discussed, steady wind speed was 25 knots. Fetch, as shown in Figure 20, was between 1 and 1.5 nautical miles depending on variations in the wind direction. For the JONSWAP calculation, a fetch of 1.5 nautical miles was used. When these equations are exercised for the conditions of 25 knots steady wind speed and 1.5 nautical mile fetch, the spectrum shown in Figure 28 results.

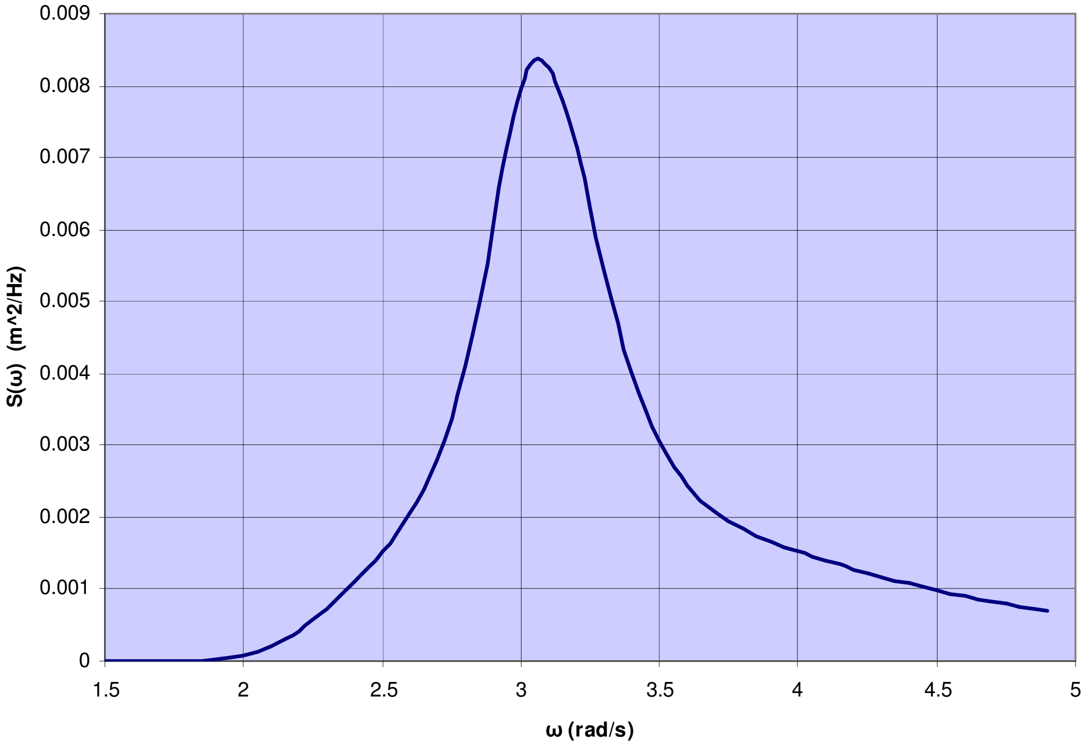

Figure 28 JONSWAP Wave Spectrum for 25 kts Wind and 1.5 nautical miles Fetch.

To calculate wave height:

$$H_{1/3} = 4 \cdot \sqrt{M_o}$$

$$M_o = \int_{-\infty}^{\infty} S(\omega)$$

$$M_o \approx \zeta^2 = 1.67 \times 10^{-7} \frac{U^2}{g} x$$

-or-

Where: $H_{1/3}$ is significant wave height,
U is steady wind speed,
x is fetch,
g is gravity,
ζ is the significant wave height,
ω is frequency, and
M_o is the area under the JONSWAP spectrum curve.

Based on the JONSWAP Wave Spectrum the significant wave height that results from exposure of the inner harbor to 25-knot winds over a 1.5 nautical mile fetch is 1.25 feet. The peak period is 3.0 seconds. For perspective, JONSWAP wave heights developed for wind speeds from 5 to 35 knots over fetches of from 1 to 2 nautical miles are shown in Figure 29. This figure shows that the reported wind speeds produce waves of 1 to 1.5 feet when blowing over the northwest harbor

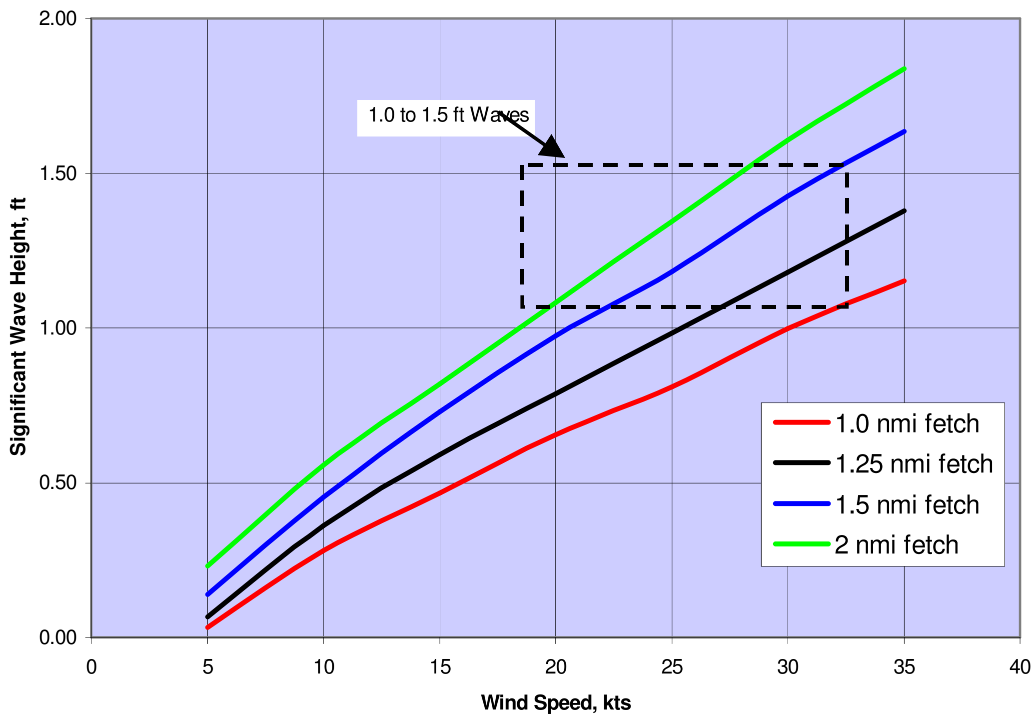

Figure 29 JONSWAP Wave Height Development

Refer again to passenger photograph #3, Figure 21, it appears that the LADY D is traveling in the direction of the waves. Stern to the seas. The captain, Mr. Deppner, and the front passenger on the port side are visible in photograph #3. The direction of this photograph is approximately due east as shown in Figure 20. Below, in Figure 30, is the estimation of the position of the LADY D relative to wind and waves immediately prior to the capsizing. Witness interviews also confirm that LADY D was running with the waves prior to executing a turn to port. As a final point, wind direction was from about 300° true. This type of wave is wind generated and the wave will run in the direction of the wind.

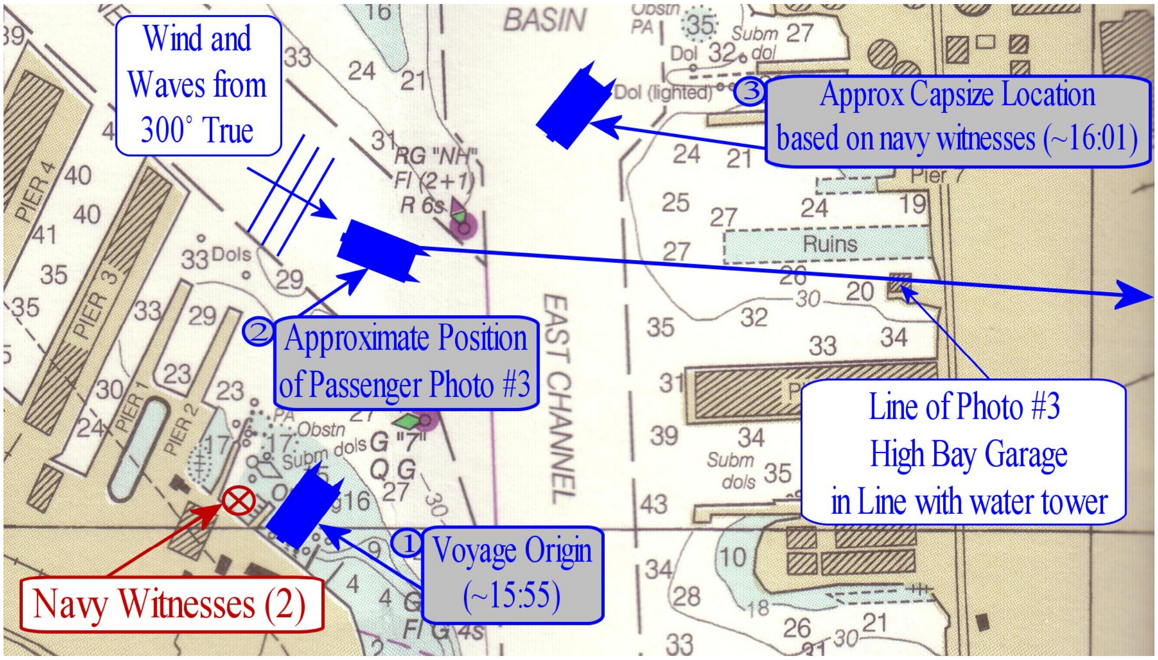

Figure 30 Estimation of Lady D Heading at Passenger Photograph #3

<u>**Bottom Line: the simulations and dynamic analysis use 1.25-foot waves at 3.0-second period coming from 300° true, having the JONSWAP spectral shape.**</u>

6.5 Ship Control

6.5.1 Ship heading

Two information sources were examined when estimating the speed and heading of LADY D including passenger photograph #3 and witness interviews.

According to witness interviews, the LADY D was running with the wind, then executed a turn to port during which the capsizing occurred. The estimated heading of 30° true as shown in Figure 30. With regards to the complete series of events, this turn is the only event important to the simulation and dynamic analysis. The reason is that the turn places LADY D port beam to wind and waves immediately prior to capsize to starboard. The witness and passenger interviews that NTSB provided are included in Appendix D.

As already discussed in section 6.2 Assumptions and Simplifications, the vessel was simulated traveling in one direction. It was not turning during the simulation. This simplification is not conservative, but was necessary to facilitate the dynamic analysis.

6.5.2 Ship Speed

In the witness and passenger interviews, Mr. Deppner stated that they operate at 6 knots. A speed of 5 knots was used in the simulation and dynamic analysis based on an estimate of 18% speed loss in wind, waves and during a turn. Although not yet verified in this simulation, the dynamics of the simulation are insensitive to small speed changes, i.e. similar results would very likely be achieved at 3, 4, 5, or 6 kts. This has been JJMA's experience with general analysis of low speed operability.

Bottom Line: the simulations and dynamic analysis were done with Lady D traveling at 5 knots in a straight line with port beam to wind and waves.

6.6 Simulation

6.6.1 AQWA Software

The dynamics of the LADY D were simulated using the AQWA suite of ship dynamics software. AQWA Drift, a subprogram of the suite, is a Computational Fluid Dynamics program, able to solve ship motions problems as a time history, by calculating the hydrodynamic and aerodynamic response of a moving vessel subjected to waves, wind and current.

The AQWA simulation is performed as a series of time-steps. At each time-step, all of the forces on the vessel are calculated and constitute the input conditions for the next time step. In this way, hydrodynamics, aerodynamics and instant stability characteristics are accounted and applied to determine the result.

6.6.2 Simulation Conditions

The previous sections discuss in detail the derivation of the simulation conditions. To summarize, the simulation used:

1. A 3-D panel model of the LADY D geometry
2. The mass properties of the LADY D at the time of the capsizing
3. Steady wind speed of 25 knots with gusts to 42 knots from 300° true represented by the Davenport Wind Spectrum.
4. Significant wave height of 1.25 feet at 3.0 second period coming from 300° true having the JONSWAP spectral shape
5. The LADY D was traveling at 5 knots in a straight line with port beam to wind and waves

Initially, the LADY D was simulated as operating smoothly at the known speed and course. The vessel was in a steady state condition. Within 1 second of starting the simulation wind and waves were added.

Capsize events are transients, non-recurring, short duration events, that are likely caused by a specific sequence of events. In order to capture the event, the simulation at the known speed and heading was repeated 20 times with variations in the initial simulation wind and wave conditions.

The AQWA simulation is performed as a series of time-steps. At each time-step, all of the forces on the vessel were calculated and constitute the input conditions for the next time step. In this way, hydrodynamics, aerodynamics and instant stability characteristics are accounted and applied to determine the result.

Prior to simulation, it was anticipated that each simulation will run for approximately 15 minutes real time at a ½ second time-step. It turned out that the simulations were run for 2 minutes at a ¼ second time-step. The time series data from the simulations are provided for preservation or additional analysis.

6.7 Results of Dynamic Analysis

The simulations and analysis show that the dynamic effects of wind and waves acting on the LADY D at the time of the capsizing were sufficient to cause capsize. The condition of 1.25 foot wave chop at a peak period of 3.0 seconds and 25 knot steady wind, gusting to 42 knots, aligned to the port beam showed capsize in 100% of 20 simulations. The average time to capsize was 23.7 seconds. The fastest time was 2.5 seconds. All capsizes occurred within 1 minute. All of the simulation run data, statistics and plots are in Appendix E. A sample showing Case #2 is shown in Figure 31.

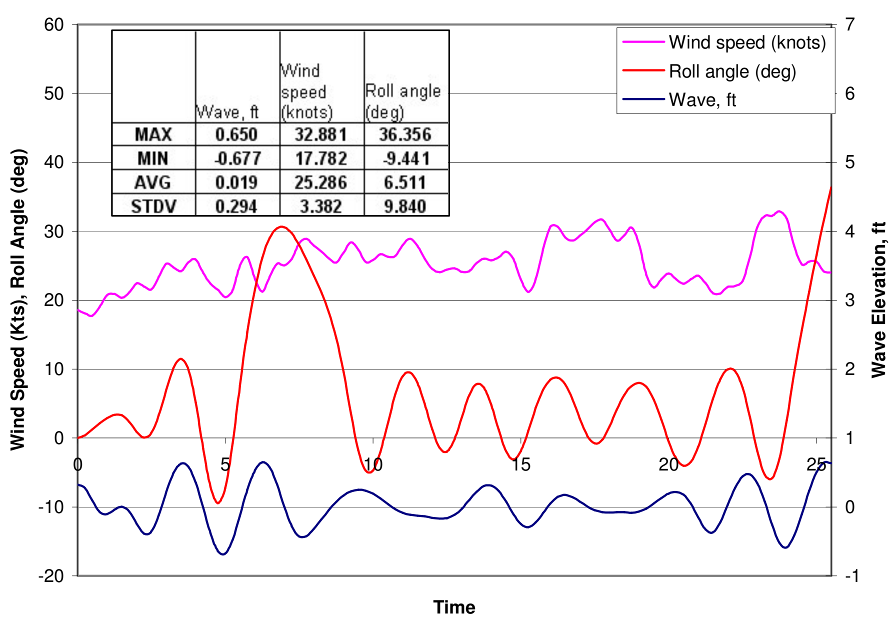

Figure 31 Simulation Time Series Plot for Case #2

A video of the simulation for Case #2 during which LADY D capsized in 25.5 seconds is presented in Figure 32. As a physics-based engineering simulation rather than a visualization, the AQWA simulation shown does not show the wave field. LADY D is traveling ahead at 5 knots beam to wind and waves. The simulation is stored as Case_2_Simulation_Video.avi on the compact disk included with the report.

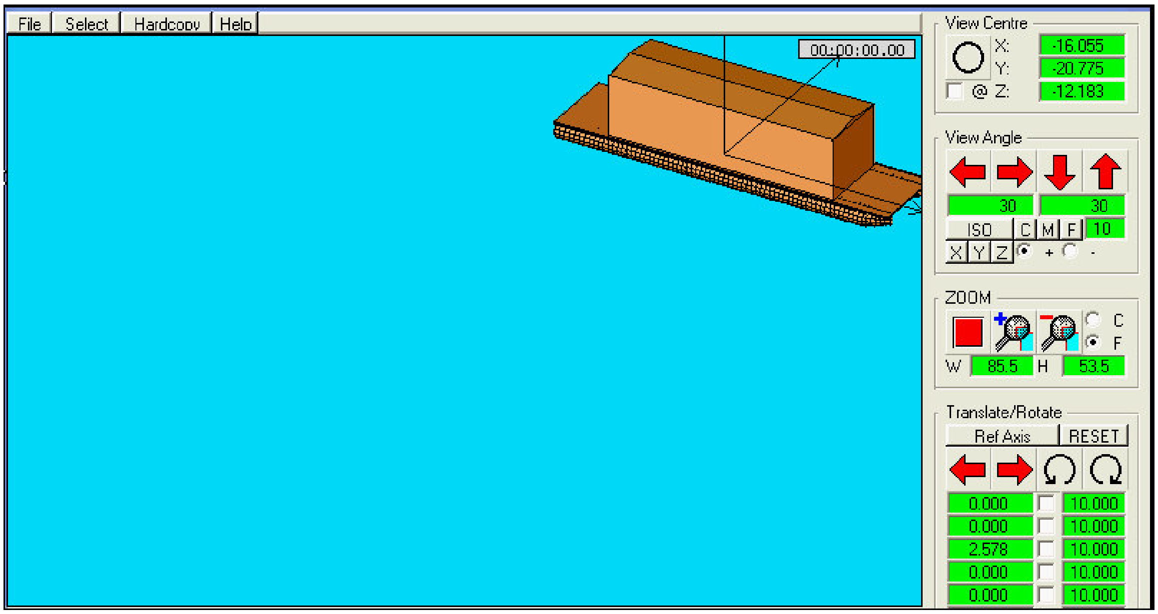

Figure 32 Video Capture of AQWA Case #2

The tabular summary of results is presented in Figure 33. The time of exposure to wind and waves needed to cause capsize in the simulation is shown. The wave, wind and last roll angle prior to capsize is shown. The maximum wave, wind and roll are shown. The maximum roll over the entire simulation and the roll angle at capsize are the same in every case because all cases capsized, but the maximum wind and wave do not necessarily occur at the time of capsize. This is not surprising. Various combinations of wind, wave and roll may result in capsize and it is very improbable that maxima would occur simultaneously. This data shows that coincidence of wind, wave and roll maxima is not a prerequisite for capsizing.

Model =	Lady D	rev -
Speed =	5	knots
Heading =	30	degrees true
Steady Wind Speed =	25	knots
Gust Speed =	42	knots
Wind Direction =	300	degrees true
Wind Spectrum =	Davenport	
Significant Wave Height =	1.25	feet
Peak Wave Period =	3	seconds
Wave Direction =	300	degrees true
Wave Spectrum =	Jonswap	

	At Capsizing Event				For Entire Simulation		
Case #	Time to Capsize (sec)	Wave Amplitude (ft)	Wind Speed (kts)	Roll Angle (deg)	Max Wave Amplitude (ft)	Max Wind Speed (kts)	Max Roll Angle (deg)
1	29.50	0.271	27.65	36.64	0.668	34.11	36.64
2	25.50	0.634	24.02	36.36	0.677	32.88	36.36
3	44.50	0.699	29.08	36.23	0.759	35.65	36.23
4	2.50	-0.043	33.13	38.81	0.357	41.50	38.81
5	6.00	0.706	28.15	39.72	0.855	32.61	39.72
6	31.75	0.528	25.21	37.93	0.786	31.26	37.93
7	45.25	0.572	30.74	38.83	0.843	42.91	38.83
8	9.75	0.349	19.94	41.14	0.621	35.31	41.14
9	41.00	0.029	29.62	37.92	0.564	33.73	37.92
10	24.00	0.627	29.04	36.81	0.753	32.87	36.81
11	36.25	0.026	21.06	35.66	0.803	37.77	35.66
12	38.50	0.682	27.43	35.16	0.862	34.72	35.16
13	12.25	0.152	20.85	35.83	0.496	29.23	35.83
14	38.00	0.465	19.90	35.42	0.770	31.32	35.42
15	13.25	0.509	30.17	39.94	0.676	36.20	39.94
16	11.25	0.089	31.17	35.07	0.428	34.72	35.07
17	18.25	0.374	14.85	38.76	0.546	31.84	38.76
18	36.25	0.535	23.30	38.33	0.913	35.06	38.33
19	5.75	0.276	30.44	37.80	0.641	36.91	37.80
20	4.50	0.915	25.58	40.49	1.124	25.58	37.80
MIN	**2.50**	**-0.043**	**14.85**	**35.07**	**0.357**	**25.58**	**35.07**
AVG	**23.70**	**0.420**	**26.07**	**37.64**	**0.707**	**34.31**	**37.51**
MAX	**45.25**	**0.915**	**33.13**	**41.14**	**1.124**	**42.91**	**41.14**
STDV	**14.71**	**0.269**	**4.81**	**1.85**	**0.179**	**3.88**	**1.72**

Figure 33 Dynamic Analysis Results

Wave amplitude and wind speed vs. exposure time to capsize are plotted in Figure 34. There is no apparent correlation. This implies that no specific combination of simulated wind and waves immediately caused capsize.

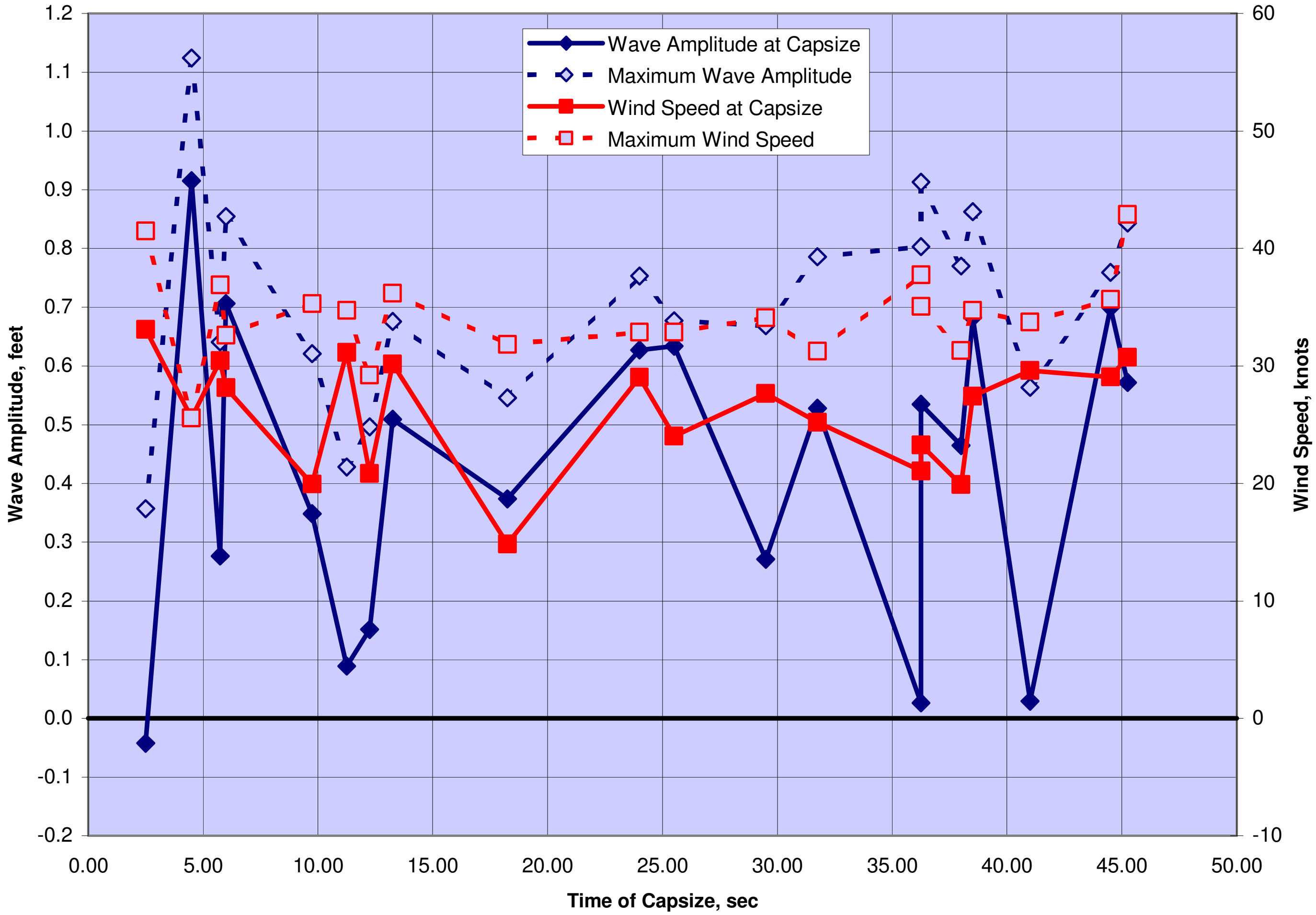

Figure 34 Wave Amplitude and Wind Speed vs. Time to Capsize

Twenty simulation runs should be sufficient to expose any trends or relationships between wind, wave and time to capsize. More simulation runs would increase the statistical confidence in the results, but may or may not reveal trends or relationships. A histogram showing how many simulated capsizes occurred between 0 and 10 seconds, 10 and 20 seconds, etc. is shown in Figure 35. The histogram does not show a trend. Absence of a trend indicates that any exposure duration to wind and waves from the port beam could result in capsize.

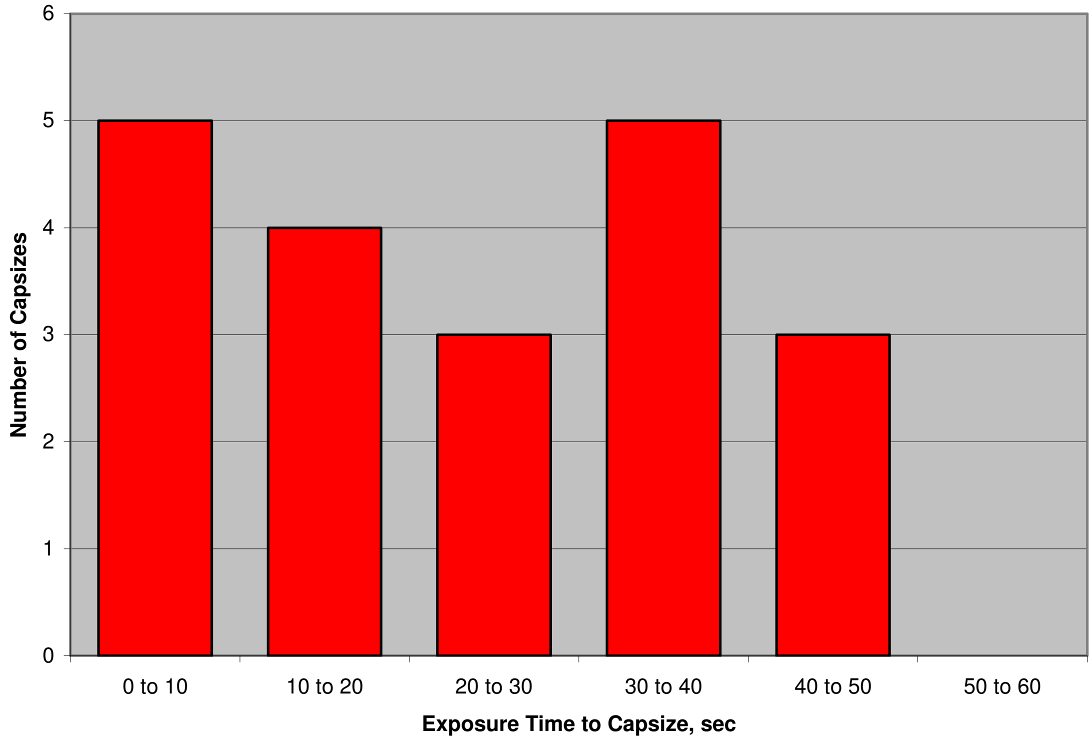

Figure 35 Exposure Time to Capsize Histogram

A histogram of the number of capsizes that were simulated at various wave amplitude bands is shown in Figure 36. The wave amplitudes shown those at LADY D at the time of capsize. Jonswap waves of 1.25 feet significant wave height and 3.0 second period were input to the simulation. The average amplitude of this wave is 0.4 feet. The relationship between significant wave height and average wave amplitude is:

$$\text{Average Amplitude} = 1.25 \times \text{Significant Height} / 2$$

Based on the twenty simulations, wave amplitudes between 0 feet and 0.8 feet (wave heights of 0' to 1.6') occurred at the time of capsize in 18 of 20 cases. Beam exposure to waves of 3 second period excite roll in LADY D. The wave amplitude at the LADY D at the time of capsize does not have to be large in order to cause capsize. The low number of wave amplitudes in the 0.8 to

1.0 foot band is due to the fact that higher waves occur less often. The wave simulation time series can be reviewed in Appendix E.

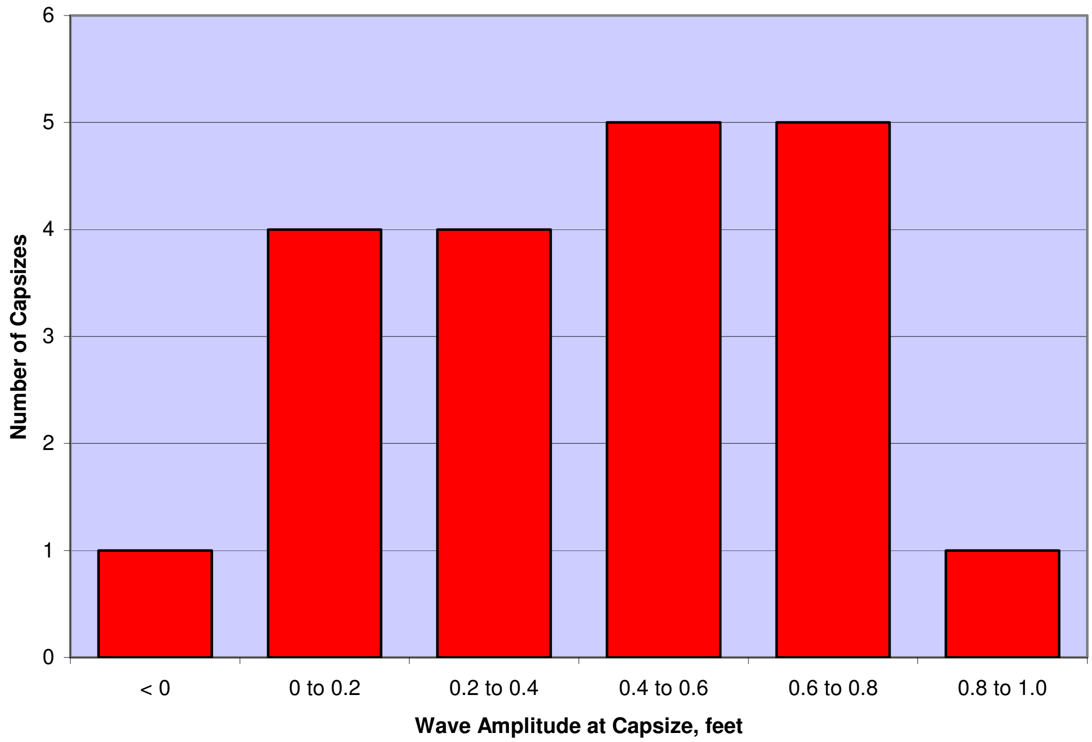

Figure 36 Wave Amplitude Histogram

A histogram of the number of capsizes that were simulated at various wind speed bands is shown in Figure 37. The wind speeds are those at the time of capsize. The simulated steady wind speed was 24 knots with gusts to 42 knots. Based on the twenty simulations, wind speeds below 24 knots could cause capsize. Fourteen cases had wind speeds above 24 knots at the time of capsize. With the exception of Case #20, the maximum gust over the duration of the simulation did not occur at the instant of capsize. The wind simulation time series can be reviewed in Appendix E.

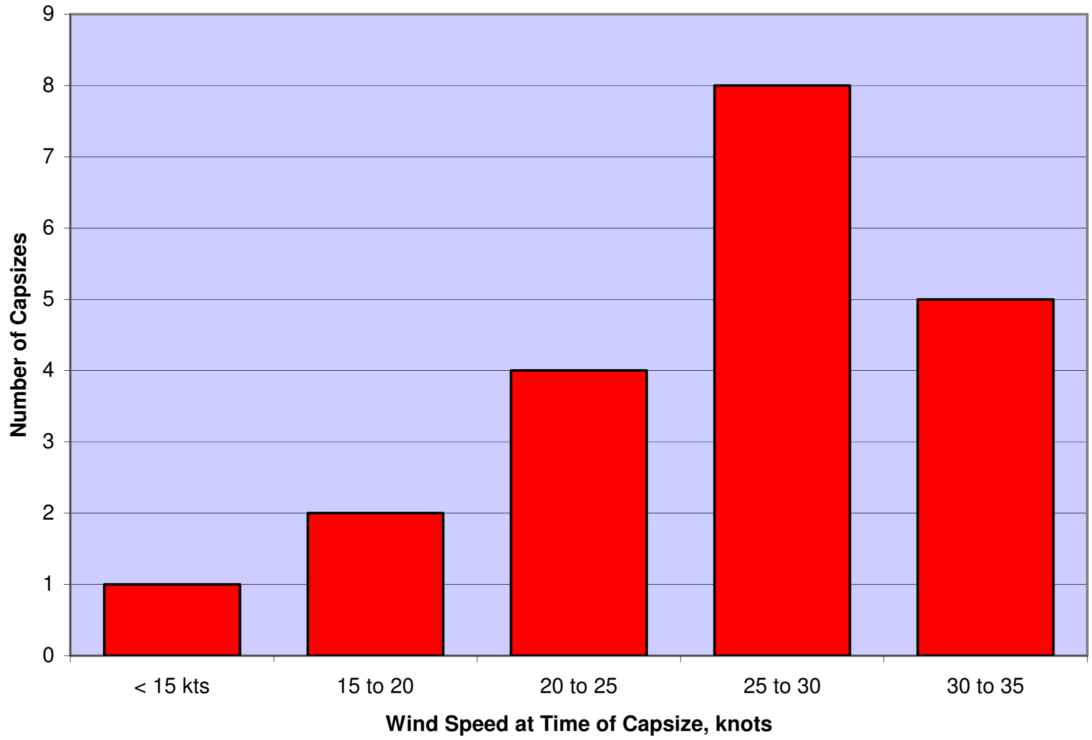

Figure 37 Wind Speed Histogram

7. Conclusions and Recommendations

The review of the existing stability documentation for LADY D, RAVEN, and FELLS POINT PRINCESS (PATRICIA P), and the errors contained therein, is indicative of a breakdown in the process employed to certify that a pontoon vessel, such as the LADY D, has adequate stability for its intended service. Proper application of the governing federal regulations would most likely have resulted in a fewer number of passengers the LADY D was certified to carry. At the same time, however, it appears that the definition of the average weight of a passenger provided in the regulations (140 pounds) may not adequately represent today's American population, based on recent news reports, and it's use in the calculations would lead to overstating a vessels ability to carry passengers.

The static stability analysis performed on the LADY D shows that the vessel failed to meet the requirements of 46CFR 178.340 for pontoon vessels operating in protected waters. The analysis assumed the vessel was loaded with 25 passengers weighing an average of 140 pounds each as permitted by her stability letter issued on March 28, 1996. The analysis showed that if the passengers were moved to either the extreme starboard or port positions as required by the test, the vessel would rollover. That the actual weight of the passengers aboard at the time of her capsizing was 168.4 vice 140 pounds only exacerbates the situation.

Further calculations based on the current regulations indicate that the maximum number of passengers (including crew) the LADY D could safely carry was 15 vice 25 as stated on her certificate. Again, these calculations were performed assuming an average passenger weight of 140 pounds.

The available weather data, weather observations, photographs and numerical representations of the weather are consistent and were simulated with high degree of confidence. Witness observations and photographs were sufficient to estimate ship speed and heading with good confidence. Photographs and records were sufficient to estimate vessel weight and intact dynamic stability with a high degree confidence. The dynamic effects of wind and waves acting on the LADY D at the time of the capsizing were sufficient to cause capsize. The condition of 1.25 foot wave chop at a peak period of 3.0 seconds and 25 knot steady wind, gusting to 42 knots, aligned to the port beam showed capsize in 100% of 20 analyzed cases. The average time to capsize was 23.7 seconds. The fastest time was 2.5 seconds. All simulations capsized within 1 minute.

The dynamic analysis discussed in Section 6, was limited in scope to examination of the vessel in the condition at the time of her capsizing and includes 25 passengers at an average weight of 168.4 pounds each. A logical extension of the dynamic analysis would be to include the condition where the vessel is loaded with 15 passengers at an average weight of 140 pounds to see if the vessel would capsize under the same sea and weather conditions. Such an analysis would provide some measure of assurance that the static stability criteria provided in the federal regulations is adequate and sufficiently conservative to account for the dynamic environment when properly applied to vessels like the LADY D.

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APPENDIX A
PHOTOS OF LADY D SURVEY – 11 MAY 2004

See CD-ROM “Report on the Capsize of the Passenger Vessel Lady D” for Electronic Files

APPENDIX B
Weight Estimates for Individual Components

See CD-ROM "Report on the Capsize of the Passenger Vessel Lady D" for Electronic Files

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APPENDIX C
GHS Output from Static Stability Analysis

See CD-ROM "Report on the Capsize of the Passenger Vessel Lady D" for Electronic Files

APPENDIX D

Witness Testimony provided by NTSB

See CD-ROM "Report on the Capsize of the Passenger Vessel Lady D" for Electronic Files

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Identification of Persons in Transcript:

Interviewers

Mr. Turrell: NTSB investigator

LCDR Hammond: USCG investigator

Mr. Woody: NTSB investigator

Witnesses

Mr. Depner: Captain of the *Lady D*

Mr. Homan: Mate of the *Lady D*

Chief Scardina and Chief Johnson: Witnesses to accident from shore (navy reserve pier)

SERGEANT ACOSTA: Passenger on Lady D who took pictures before capsizing

Speed:

MR. TURRELL: Okay. What is the maneuver in this vessel like and describe the speed and the, and the response of the vessel and how much power you have and turning ability?

MR. DEPPNER: Well, it is a Honda, I think it is a 90 horsepower and it responds rather well. In the wind sometimes, maybe, you don't get the same responses that you do otherwise, but under normal circumstances, it handles very well, to go port to starboard side. And we operate at the six knots, about 7.2 miles an hour max. And all the Seaport taxis do that. And we know pretty well within, you know, sort of latitude of exactly where that is on the accelerator and stuff, so, that is exactly what we do.

Heading

CHIEF SCARDINA: And we get outside about 1600, you know, thunder clap, you know, the wind really picked up, started gusting pretty hard, I'm guessing about 45, 50 knots. And we're looking out and there's this water taxi coming from the harbor – or that's where it appeared to be coming from – from the harbor direction, and it was passing right – you know, there was a green – a green tanker tied up along the pier directly across from us, and he was passing by that ship. Once he got around, almost to buoy seven, and the skipper went into a port turn, and at that point, the winds were gusting and got up under her – under the starboard side and buked a couple times.

Course we had some white caps out there. White caps were bringing it up and the wind got up underneath her starboard – starboard pontoon and flipped him over. At that point I grabbed the cell phone, called 911, told them I needed marine rescue, Coast Guard, fire, whatever you've got, get it out there.

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MR. WOODY: Forty-two years. Tell us about the day that the accident happened. What you remember – what time was it and what were you doing and where you were at, and –

CHIEF JOHNSON: Okay, between quarter of and ten of four, Chief Scardina and myself were at the back of the reserve center, out of the doorway. And we were just out there talking about the storm, the approaching storm and looking at the weather conditions because we heard loud thunder earlier and a gust of wind seemed to be coming on and were trying to figure out what the weather patterns were going to be.

While we were out there we noticed, out in the channel beyond where the marker buoy, that we saw there was a water going in the direction of Fort McHenry. But even though, you know, they were all the way over on the other side of the channel alongside a large green marine vessel that was tied up, when we saw a large – looked like a large wall of water – when I say that, I mean a combination of rain and wind, the water was very choppy and it had a swift current going out towards the Fort.

And when I saw the pontoon boat, I said to Chief Scardina, what is he doing out here in this kind of weather? Somebody had to have a marine warning or something. And it looked like he was about to make a left turn and it looked like he was trying to turn around and go back up into the inner harbor or at least make a left hand turn and that's when we noticed that when he turned into the wind it seemed like the wind lifted the pontoon – one side of the pontoon boat out of the water, and before it could come back down, it seemed like another gust took it and flipped it over and it capsized.

MR. WOODY: And you say it capsized to which side?

CHIEF JOHNSON: My recollection is that it capsized to the right side.

MR. WOODY: The right side. How quick was the capsizing?

CHIEF JOHNSON: As soon as the wind picked it up, I'd say it was less than 30 seconds. It seemed to be less than 30 seconds. Less than half a minute.

MR. WOODY: Just take this like this here, if this is raised up one time – raised up – were you looking at this sideways?

CHIEF JOHNSON: At the back. In other words, I'm looking at this at the back of the boat. So when he started to negotiate the turn like this, just as he got to this point, it seemed like it lifted it up like this. They never got a chance to settle back down.

MR. WOODY: So that's probably just a few seconds?

CHIEF JOHNSON: Right. So, I mean, from the time we saw him making the turn to when he flipped was about half a minute, by the time he made the turn to the time it flipped, it seemed to be about that.

MR. WOODY: Okay, when it laid into the wind it was just seconds right?

CHIEF JOHNSON: Seconds, right.

MR. WOODY: One or two seconds. Now, was there any kind of ship in the background?

=========

(Depner)

And we were a little behind schedule because we had about 38 people out there, and I had taken the boat, not full, but about 14, 15 people back previously, and I had got into the dock in the time frame of probably 3:45. And by the time we were loaded, we were approaching 10 of four. And the guy we call Bill, was there and we had talked that today it is going to be a little later than, you know, four o'clock, to get the last people off. But, I will be back just as soon as I can. And at about that time frame, it was maybe about 10 of four. And when I backed the boat away from the dock, which is boating dock between the two main fire boats there at Fort McHenry, instead of docking or backing out and turning to the port, I turned to the starboard because that was backing into the wind, and I had better control. And I continued to back and what I basically wanted to do was do a complete backing turn and then do as small turn as I could, to the port to go back towards Fells Point.

Well, it was in that maneuver that I heard the weather report. I am not sure where the weather report was coming from, but, I did hear get it over the radio. It was also noticeable that as I started to pull out this backing maneuver, that the wind was really picking up.

(Pause.)

MR. DEPPNER: At that point the wind really started picking up. And as I tried to continue to turn into the wind, John Glenn, one of our senior captains was on the, because the wind is beginning to pick up and everything, why don't you try to get into Henderson, get into BMC and tie up the boat. And I remember responding to that, and I said, John, that is exactly what I am going to try and do. But, it seemed regardless of what I did, the wind continued to push the boat sort of in the easterly direction because the west wind was basically that strong. And it seemed like there was a, let's think of a better word, a wall of water or a wave that seemed to be coming with enough force to almost obscure all the windows on the port side of the boat.

And I still tried to turn into the wind, but there was no turning, the boat just seemed to not do anything. And for awhile, it almost seemed like this wind was beginning to turn the boat almost in a circle, circular motion. And I am not sure if the boat went all the way around once or not. I suspect maybe it did. And then the wall of water seemed to still be there and the boat just tipped to the side. And the mate, me, and some passengers basically ended up underneath that boat.

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LIEUTENANT COMMANDER HAMMOND: And what was your heading at the time it capsized, do you remember?

MR. DEPPNER: I was starting to go back towards Fells Point and it should have been a westerly direction, but I think the heading because of the wind, was probably more of a northwest to north.

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LIEUTENANT COMMANDER HAMMOND: Which one were you going to go for, was it BMC or Henderson?

MR. DEPPNER: Well, I was going to go to BMC because that is where I was closer because that was sort of a bit further in, toward the Inner Harbor, from the Fort, and Henderson, Henderson was then quite a bit further.

LIEUTENANT COMMANDER HAMMOND: Okay.

MR. SILVER: Henderson, by the way is probably half a mile from one end to the other end.

MR. DEPPNER: Right.

MR. SILVER: Depending on where Frank was in relationship to it. BMC can be a quarter of mile away or it could be a mile.

LIEUTENANT COMMANDER HAMMOND: Okay.

MR. SILVER: Because of the way those docks are laid out.

MR. DEPPNER: And as I tried to get into that area, I couldn't even turn in that direction. And the wind seemed to be pushing me out and that is why I mentioned earlier that I was almost pushed out to be opposite the Bay Cafe area, and I said, gee, I will go into the BMC on this eastern side of the BMC area. And I couldn't even get there. And it was in that same time frame that the boat capsized.

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MR. TURRELL: Okay. And so when you left dock, what were the conditions?

MR. HOMAN: Well, if you look at the lay of the land there, we are docked at the fire, head in, so we would have had the back out. So, before I think I got even to make my announcement, we got hit with a bad wind. And I remember telling everybody to stay seated, nobody stands up. And I think the boat got turned around and was heading towards Fells Point and then the wind really picked up. And I think it blew Frank off to the right, and he did like a spiral and the wind was blowing down towards the Key Bridge. He couldn't turn the boat around to get back to the dock. So, it was pretty quick, to back up. It was just a struggle. At one point the passengers had jumped up and I remember Frank telling me earlier that if they do that, it will throw the boat out of balance and I had them sit down again. And when I felt the boat going, being thrown over to the right side, I said, to get up and go over to the right side, to balance the boat out. And at that point, the boat just went over.

MR. TURRELL: Okay. So, where, going back just for a moment, where was the wind coming from?

MR. HOMAN: The wind was coming from the west.

MR. TURRELL: Okay. Which side of the boat? What side?

MR. HOMAN: Well, from where we were, you know, we were making a spiral turn.

MR. TURRELL: Okay.

MR. HOMAN: So, when we flipped, the wind was behind us.

MR. TURRELL: Okay. So, initially the boat yielded to which direction, initially?

MR. HOMAN: As we were turning, originally when we were heading towards Fells Point, the wind was blowing us off to the right. And as we made that turn to get the wind behind us, the boat had turned to the, lisped to the right side of the, starboard side.

MR. TURRELL: Okay.

MR. HOMAN: And passengers got up and leveled it off. And I had everybody sit down and there were, we had the wind behind us, turned to make another turn to go back to the dock, I assumed he was going back to the dock, and at that point the boat was -- and again the passengers got up, went over to the starboard and at that point the boat flipped. So we did everything we could to stabilize the boat.

MR. TURRELL: Okay. Once the boat started to turn and flip, which, it went from, was yielding towards the starboard and flipped from port to starboard?

MR. HOMAN: Yes.

Passenger movements:

OFFICER SHOCKEY: Was anyone standing up just at the time?

MR. DEPPNER: No, there was nobody standing. There was no shifting of people from one side of the boat to the other. Everybody was seated and that boat capsized.

OFFICER SHOCKEY: Okay. Where was the mate?

MR. DEPPNER: The mate was in the rear of the boat.

SERGEANT ACOSTA: It was going this way, I was sitting right here behind the captain and the boat started going like that, and there was a point when the first mate, who was on the back, by that back door, the boat started rocking and he said, like, I need some people to move to this side of the boat to balance it a little bit, from this side to that side. And, but, then I guess everybody was starting to get scared and like everybody got up at once, so he said, no, sit down, sit down, everybody sit down. And then a few people got up and then he sat us back down. And then right after that, that is when I, that is when I told him, we are going to capsize. That is when I took those two pictures. And on the second picture, I don't know if you can notice, it is kind uneven. I took the pictures straight, but the boat was like this at that point, on this one. See, it kind of looks like that.

MR. TURRELL: Right.

SERGEANT ACOSTA: A little bit, well, the boat actually went that way. And it, I mean that one was scary, so that is when I stopped taking pictures. I just let my camera hang on my neck and a few seconds after that, it didn't take a minute, before the boat actually, actually capsized.

I was sitting on this side, and from what I can remember, it is like the boat went like this, I guess, on a wave or something, and then all of a sudden it just kept on going, and it fell like that. I was sitting here and I fell to this side, that is why I know that is the way it went, because I was sitting here and I fell that way. Then I stood up, as soon as it was like this, I stood up as fast I could and I reached for the window, and I was trying to open it and it wouldn't open. It had a lock on it.

Weather conditions

MR. TURRELL: Okay. When did you first notice the dark clouds?

MR. HOMAN: On the way in.

MR. TURRELL: Okay. So about 3:30.

MR. HOMAN: Roughly.

MR. TURRELL: Okay.

MR. HOMAN: But, everything looked like it was to the west.

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MR. TURRELL: Okay. Have just a couple. First of all, is there anything now that we have asked questions that we jarred your memory you would like to add? Anything that strikes you or any other comments you would like to tell us?

MR. DEPPNER: One thing I would like to offer and I don't use this word very often, and it is rogue, and I see this wind that came up all of a sudden yesterday as being one of the things that is unexpected. I thought of that word yesterday and it kept hitting me this morning and it was overall wind. It just came from nowhere. And it was all of a sudden, and it seemed like as fast as it came, it went away. It was almost like there was a spiral of wind or spiral of, a hurricane, or tornado or something of that and I know the report was 55 knots or something like that. I think it was more than that. Because I think I have been out there probably at 50, you know, I can say that the boat was leaning, you know, go in the wind and you are okay, and when you get into the dock, you know, you are away from the wind and everything. I would think that the wind that hit that boat yesterday was closer to 70.

MR. TURRELL: Okay. What was the general sea conditions, that you can give us, like the size of the chop, overall --

MR. DEPPNER: The size the chops had turned from very calm in the time frame up until almost two o'clock, until maybe chops of a foot, foot and a half. There were little light foam developing, which is not unusual. And not an indication that we shouldn't operate. But, in the, I would say -- to the time that the boat capsized, those were chops were probably much more and it happened so fast that I couldn't see it, but, I do know the wind pushing the water against the port side of the boat was sufficient to just obscure that entire side of the boat. I couldn't see anything. And I don't know what the height of the boat, about 17?

MR. SILVER: I think the windows -- The windows and the water line are probably seven.

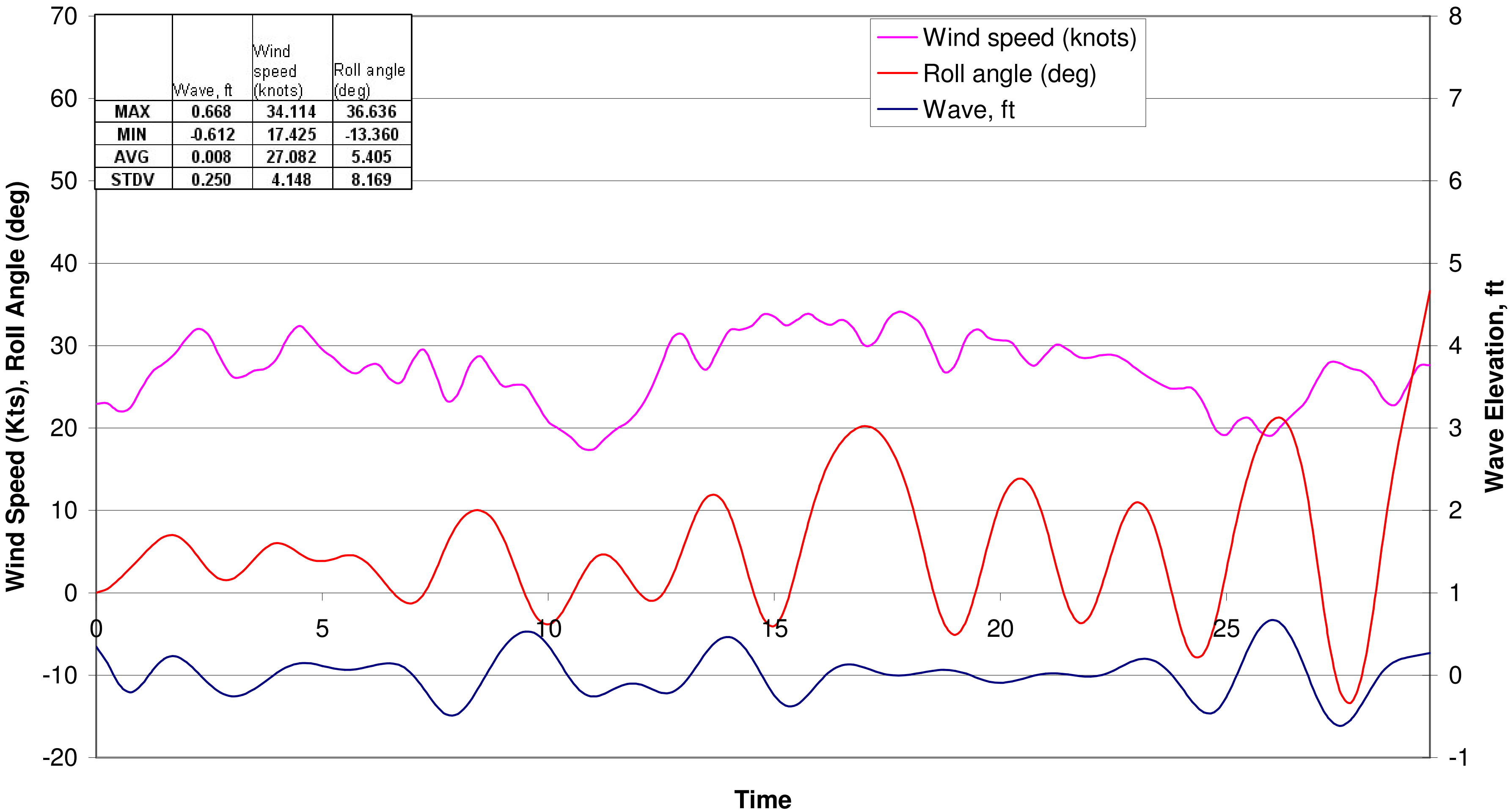
MR. DEPPNER: Yeah, it was blocked out and I don't know if that was the wind or the wind blowing the rain, or the wind blowing the water or a wave type action. It was hard to tell.

APPENDIX E
Simulation Data Time Series and Plots

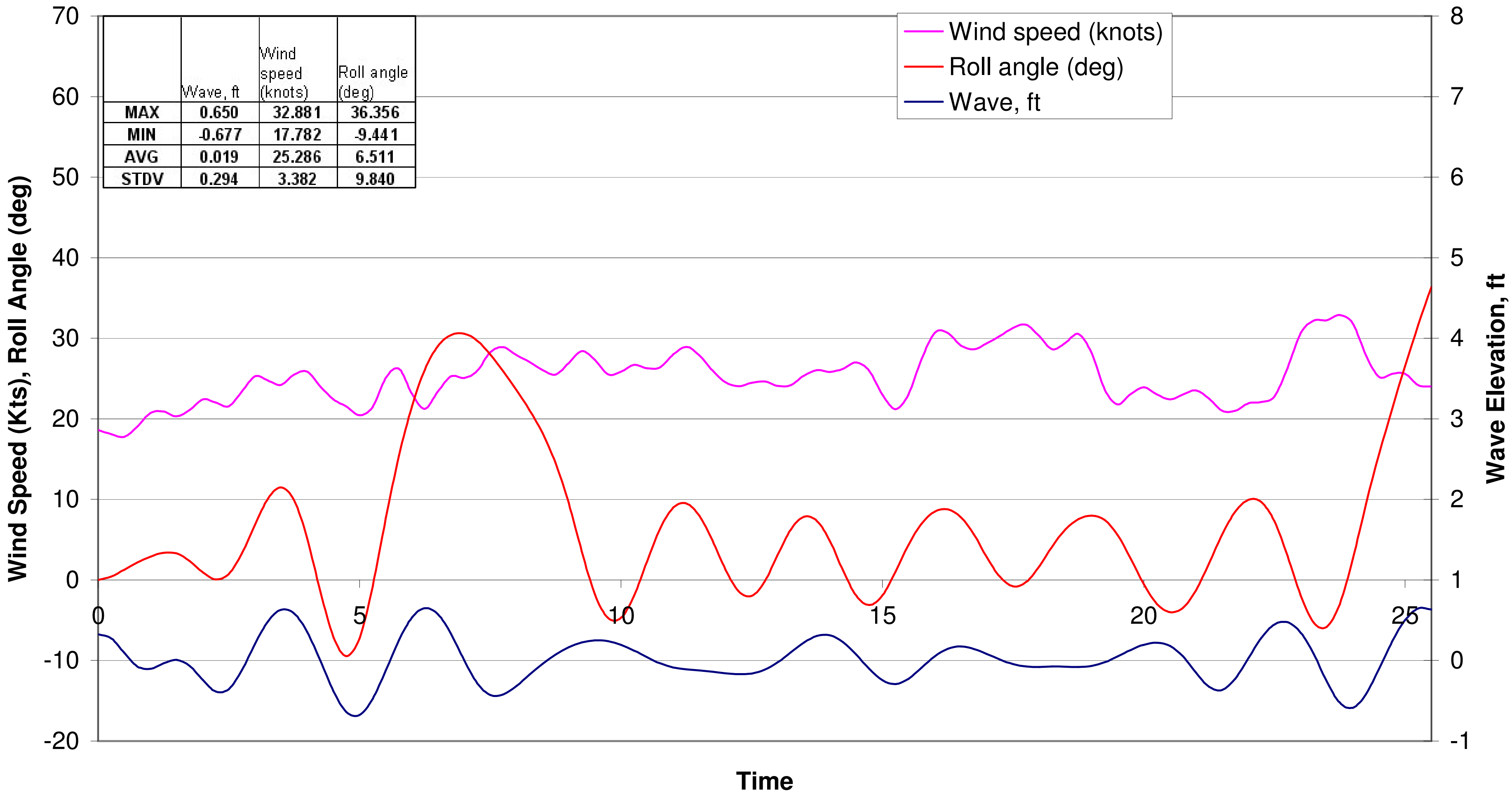
See CD-ROM "Report on the Capsize of the Passenger Vessel Lady D" for Electronic Files

CASE #1

	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.668	34.114	36.636
MIN	-0.612	17.425	-13.360
AVG	0.008	27.082	5.405
STDV	0.250	4.148	8.169



CASE #2



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.650	32.881	36.356
MIN	-0.677	17.782	-9.441
AVG	0.019	25.286	6.511
STDV	0.294	3.382	9.840

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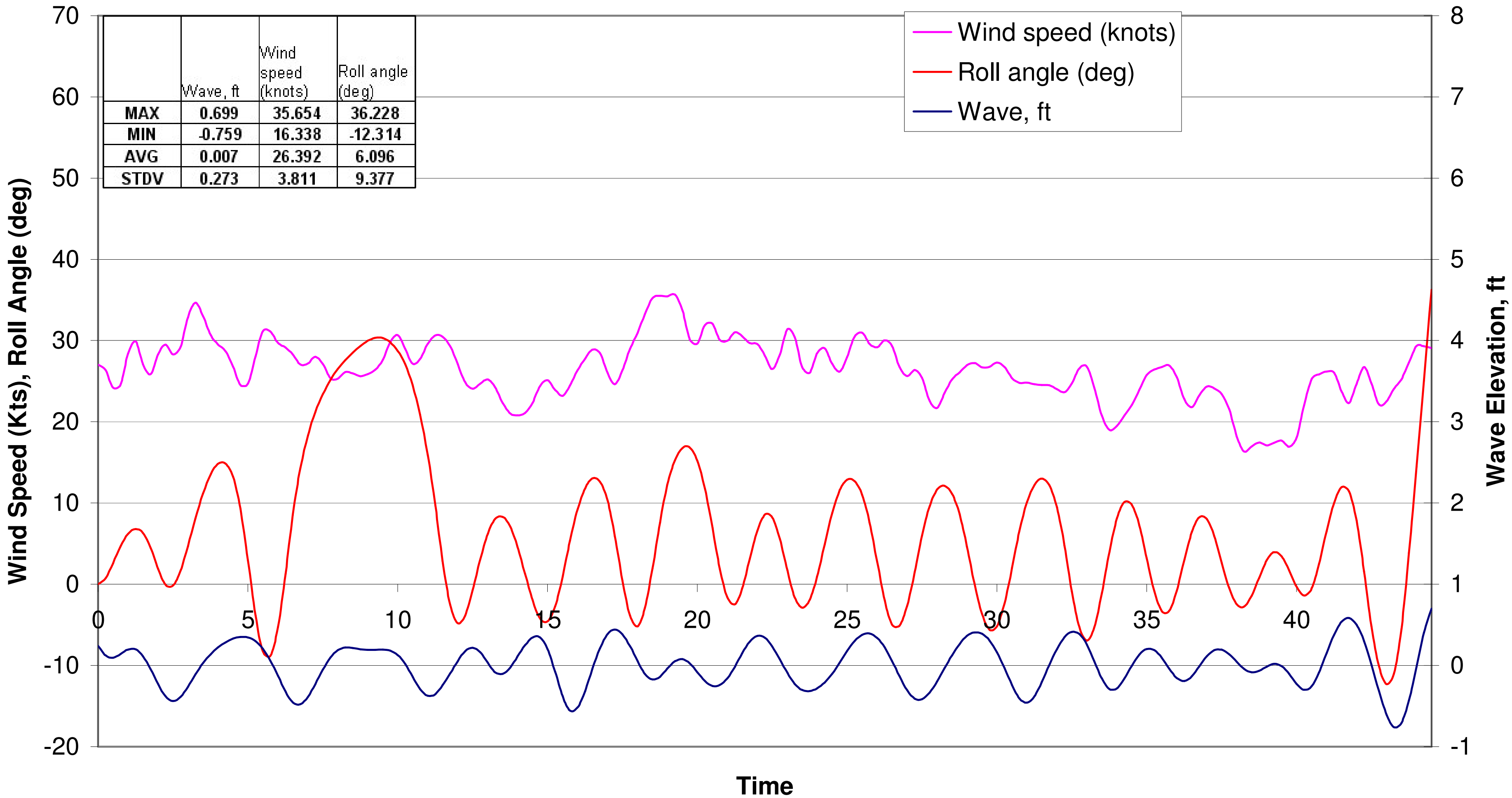
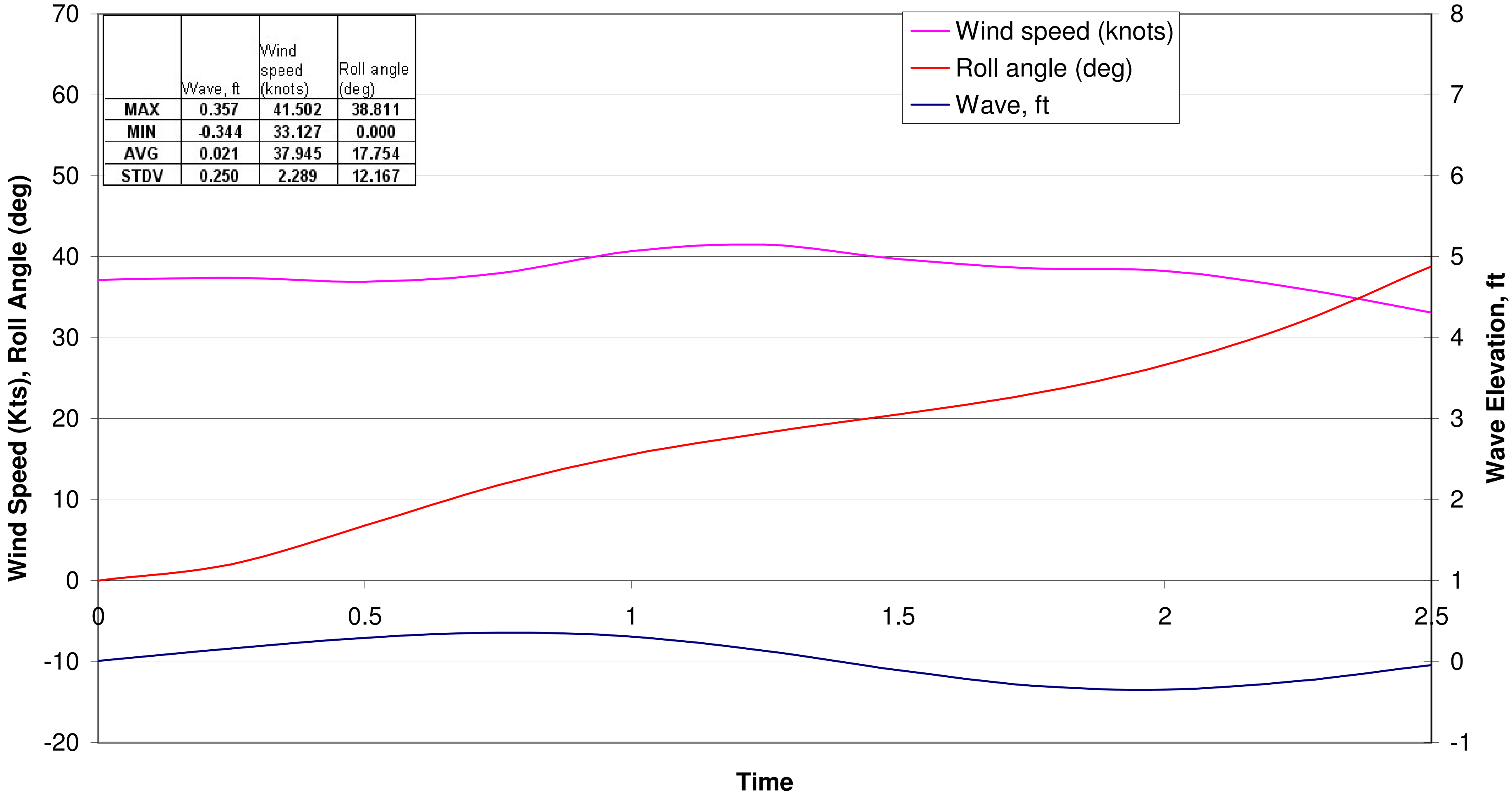
CASE #3



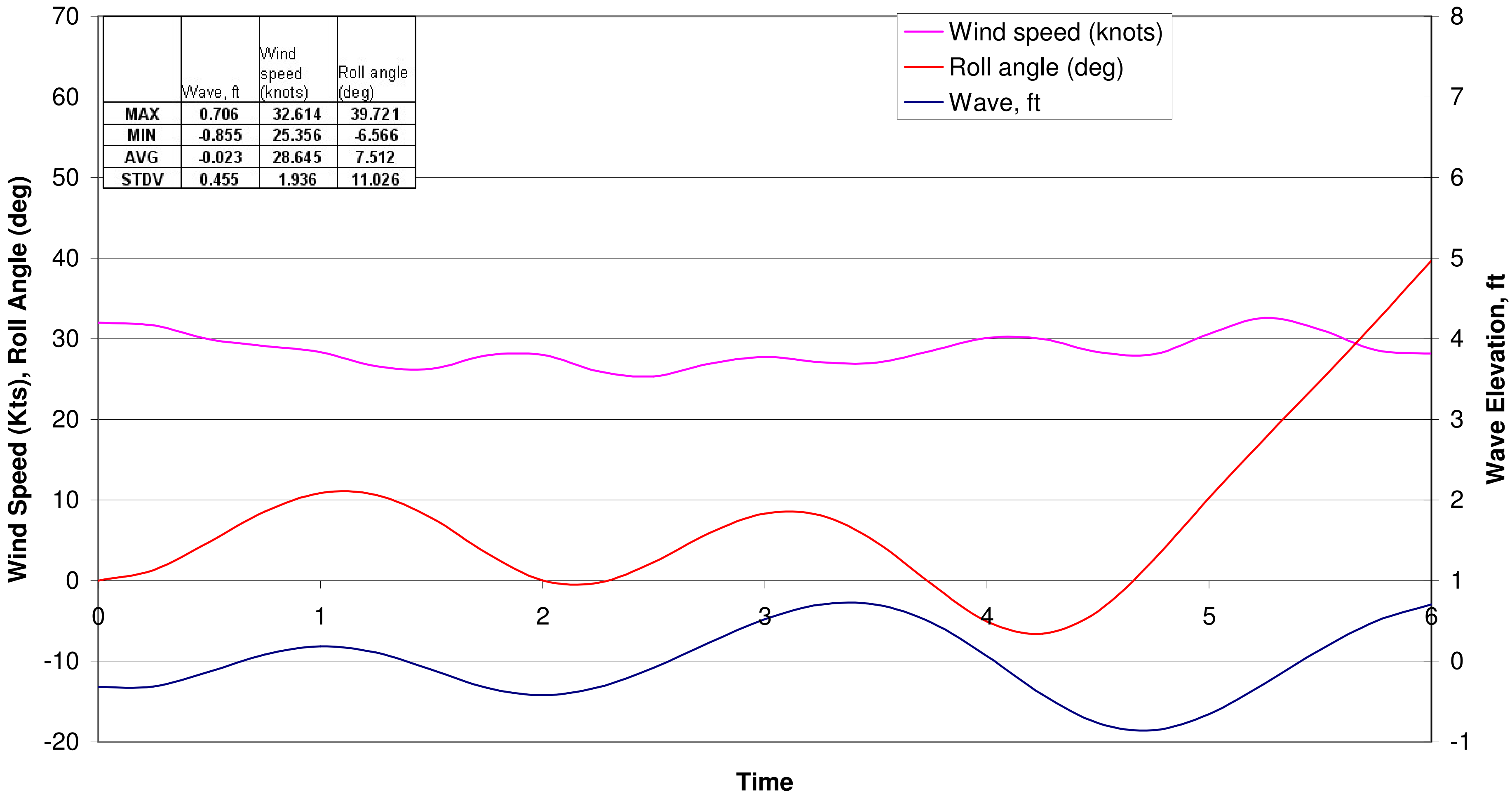
	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.699	35.654	36.228
MIN	-0.759	16.338	-12.314
AVG	0.007	26.392	6.096
STDV	0.273	3.811	9.377

CASE #4



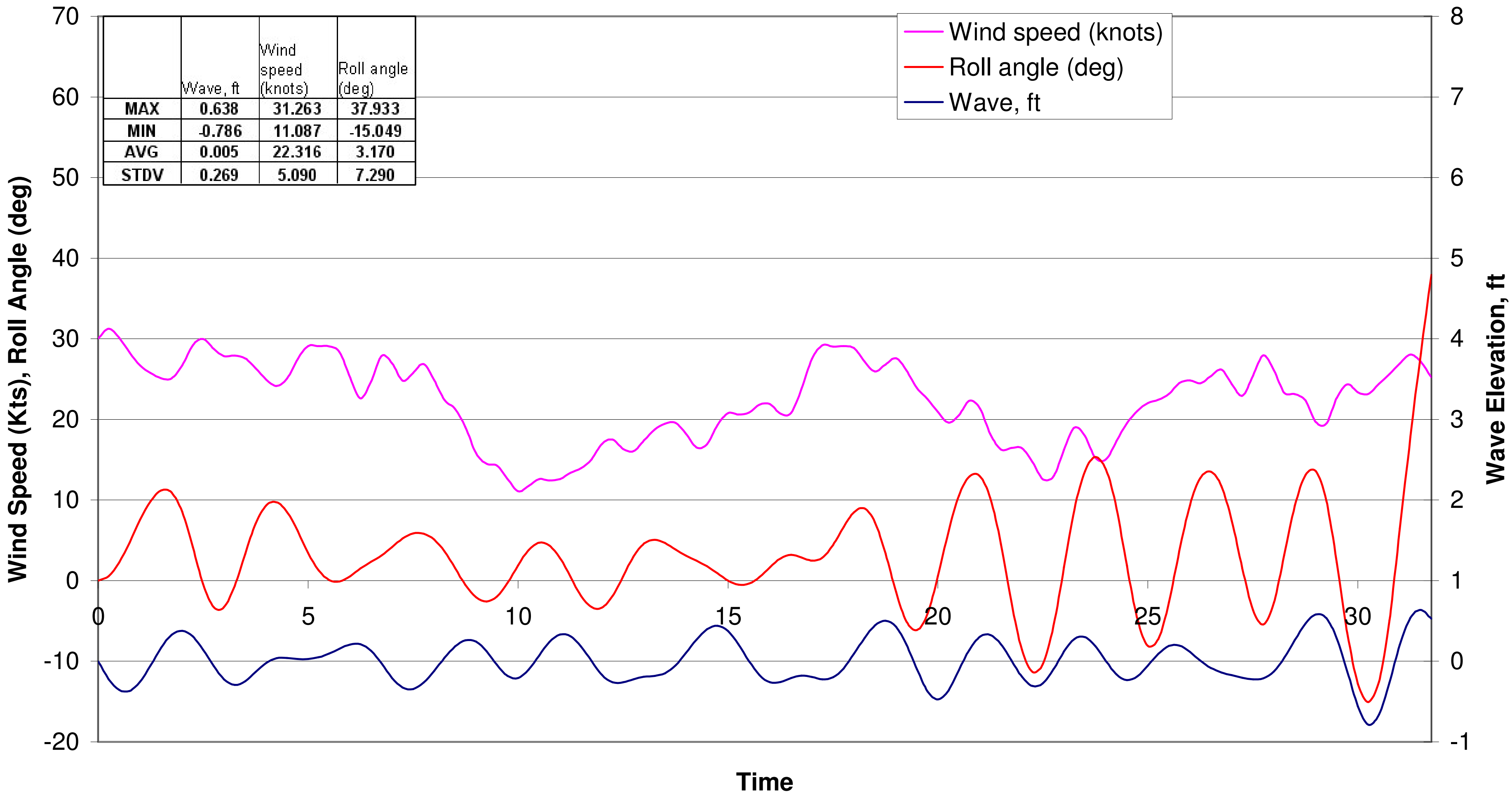
	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.357	41.502	38.811
MIN	-0.344	33.127	0.000
AVG	0.021	37.945	17.754
STDV	0.250	2.289	12.167

CASE #5



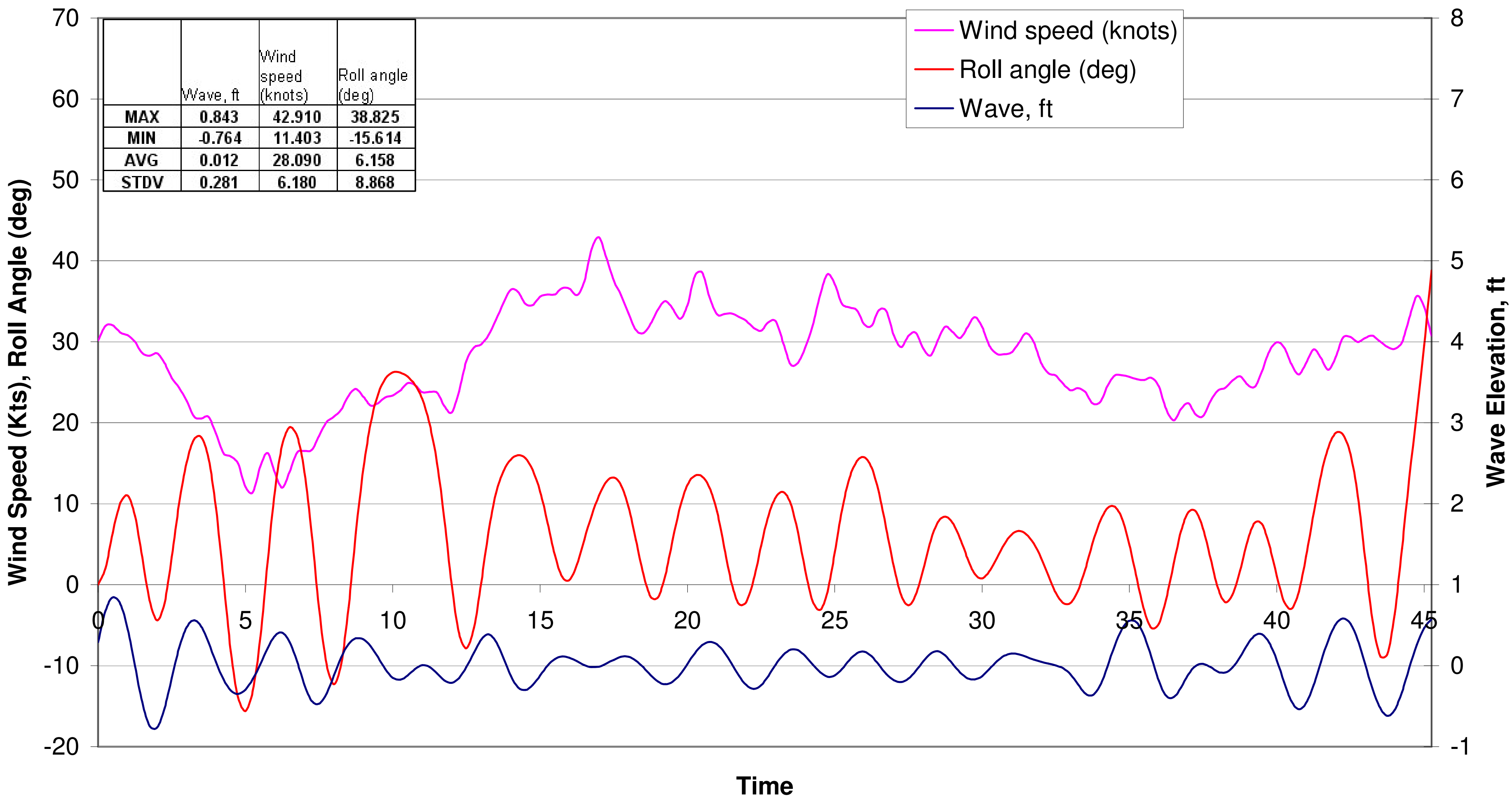
	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.706	32.614	39.721
MIN	-0.855	25.356	-6.566
AVG	-0.023	28.645	7.512
STDV	0.455	1.936	11.026

CASE #6



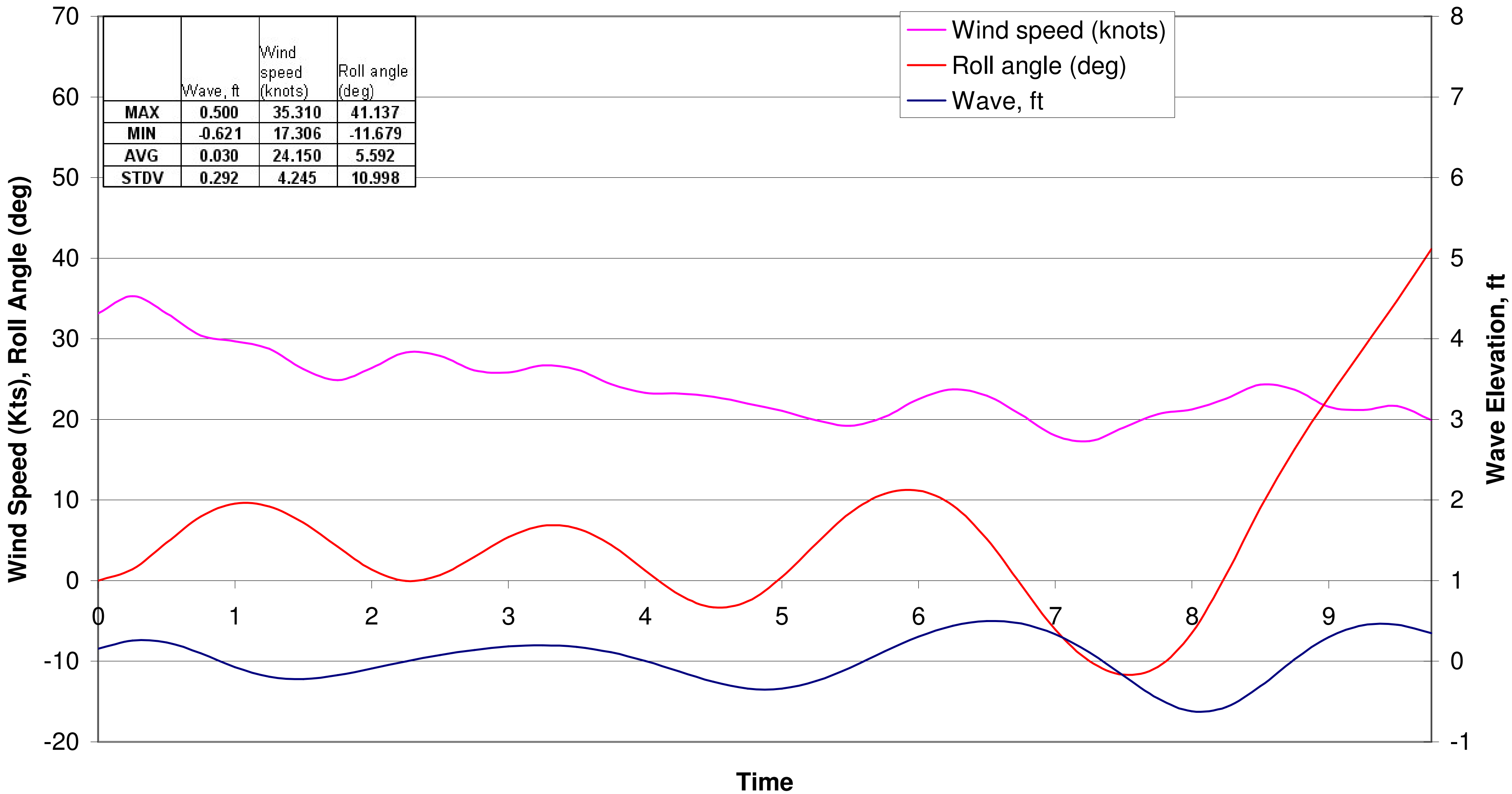
	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.638	31.263	37.933
MIN	-0.786	11.087	-15.049
AVG	0.005	22.316	3.170
STDV	0.269	5.090	7.290

CASE #7



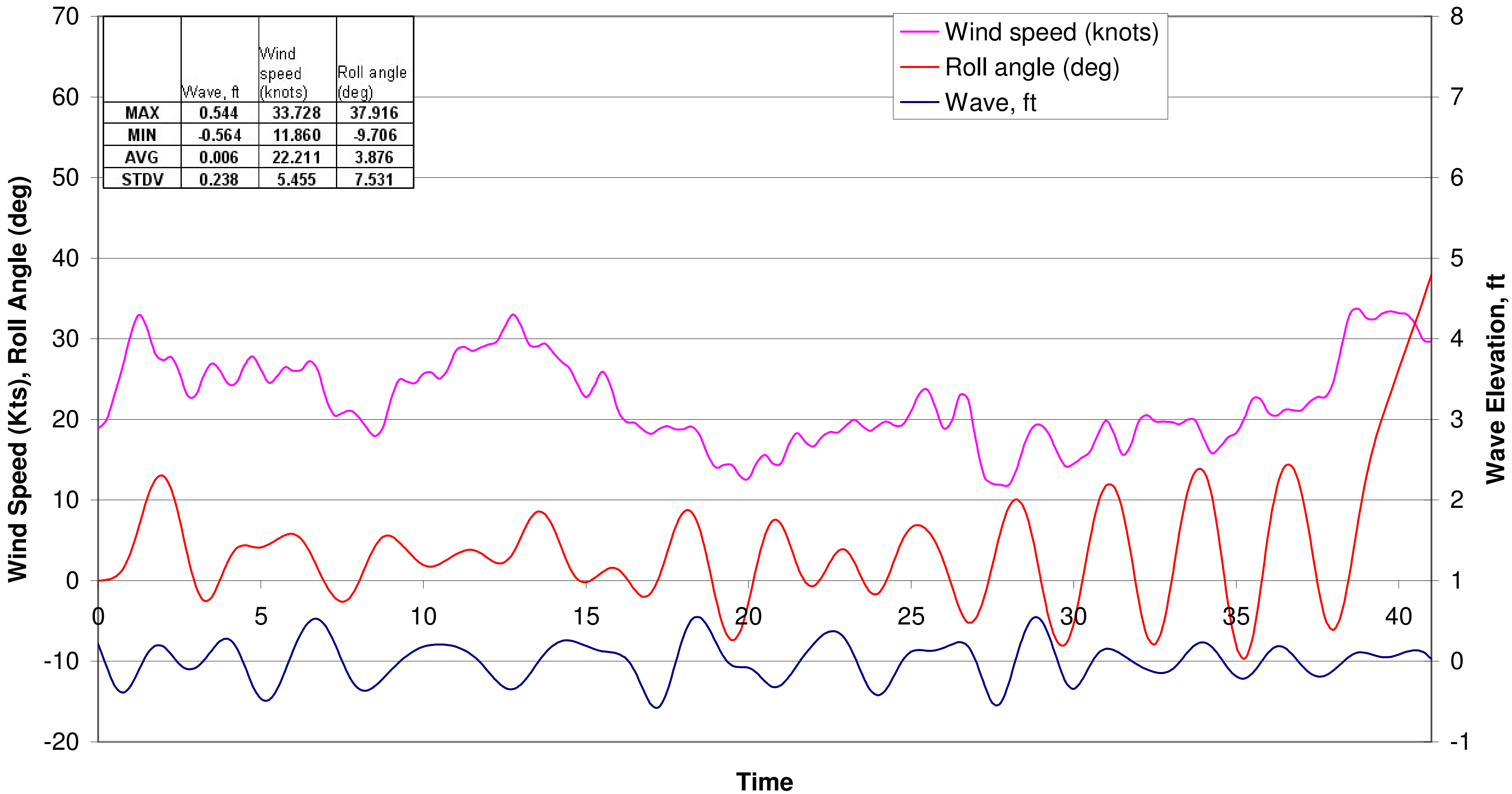
	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.843	42.910	38.825
MIN	-0.764	11.403	-15.614
AVG	0.012	28.090	6.158
STDV	0.281	6.180	8.868

CASE #8



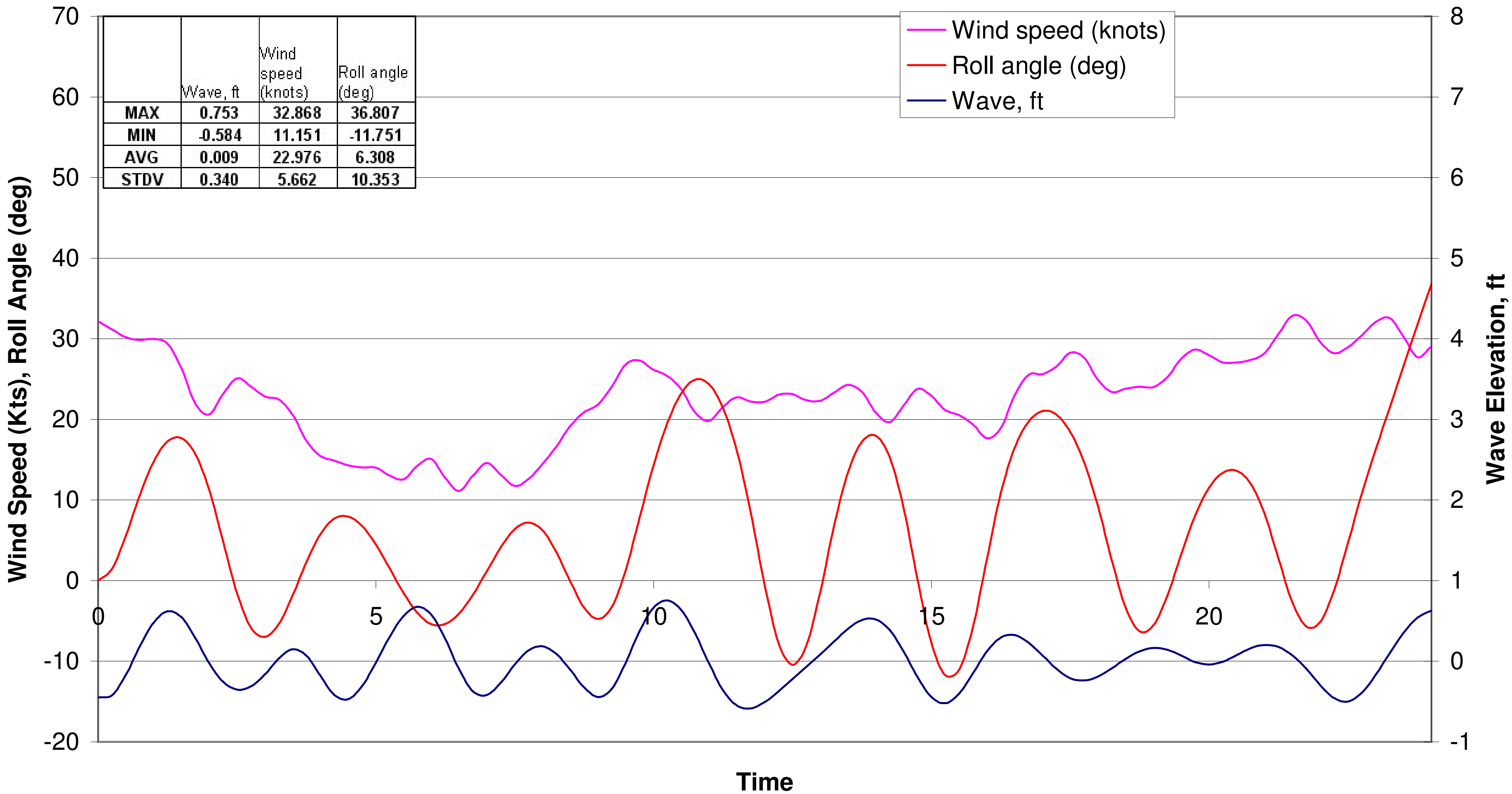
	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.500	35.310	41.137
MIN	-0.621	17.306	-11.679
AVG	0.030	24.150	5.592
STDV	0.292	4.245	10.998

CASE #9



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.544	33.728	37.916
MIN	-0.564	11.860	-9.706
AVG	0.006	22.211	3.876
STDV	0.238	5.455	7.531

CASE #10



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.753	32.868	36.807
MIN	-0.584	11.151	-11.751
AVG	0.009	22.976	6.308
STDV	0.340	5.662	10.353

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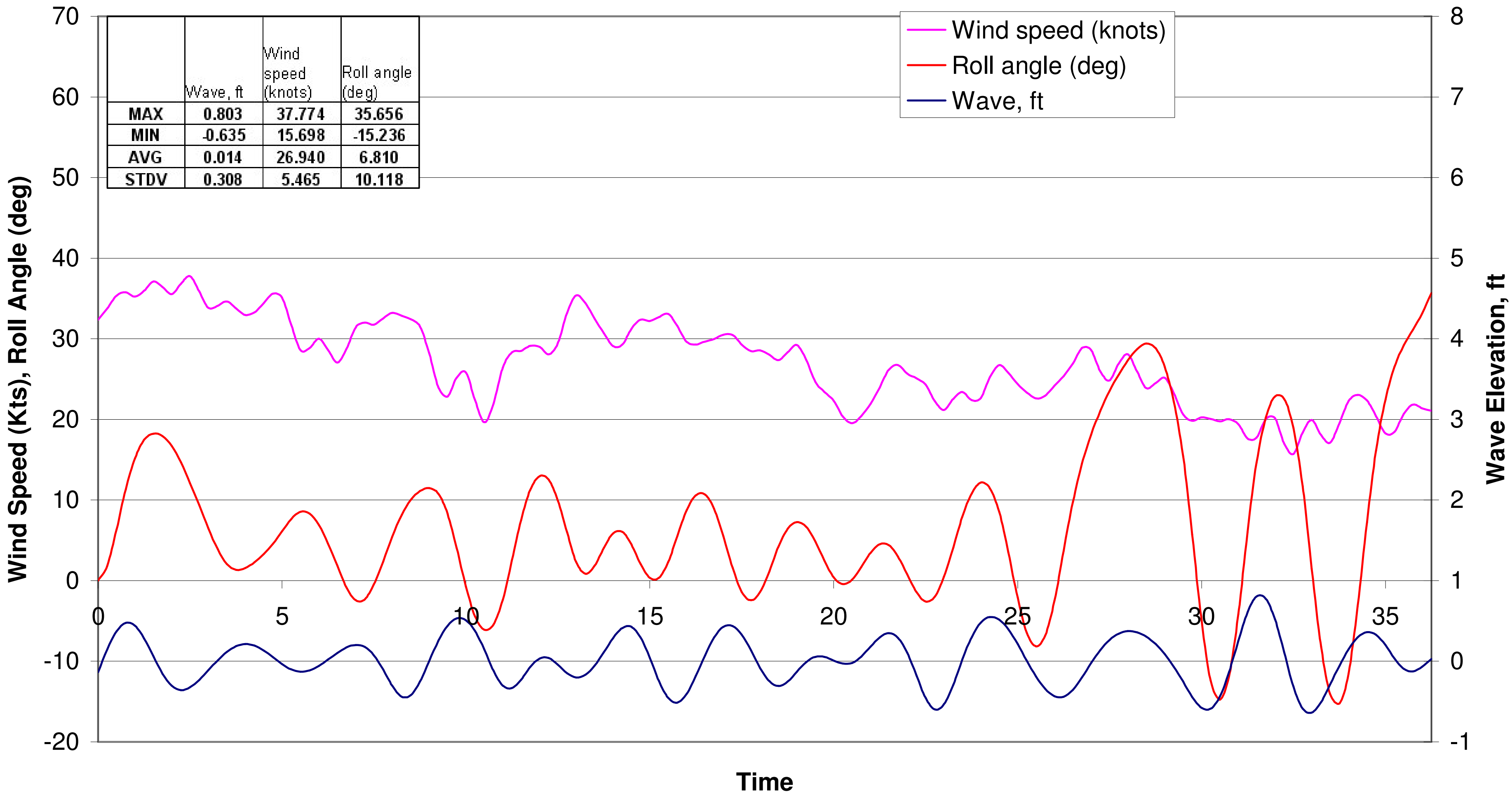
CASE #11



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.803	37.774	35.656
MIN	-0.635	15.698	-15.236
AVG	0.014	26.940	6.810
STDV	0.308	5.465	10.118

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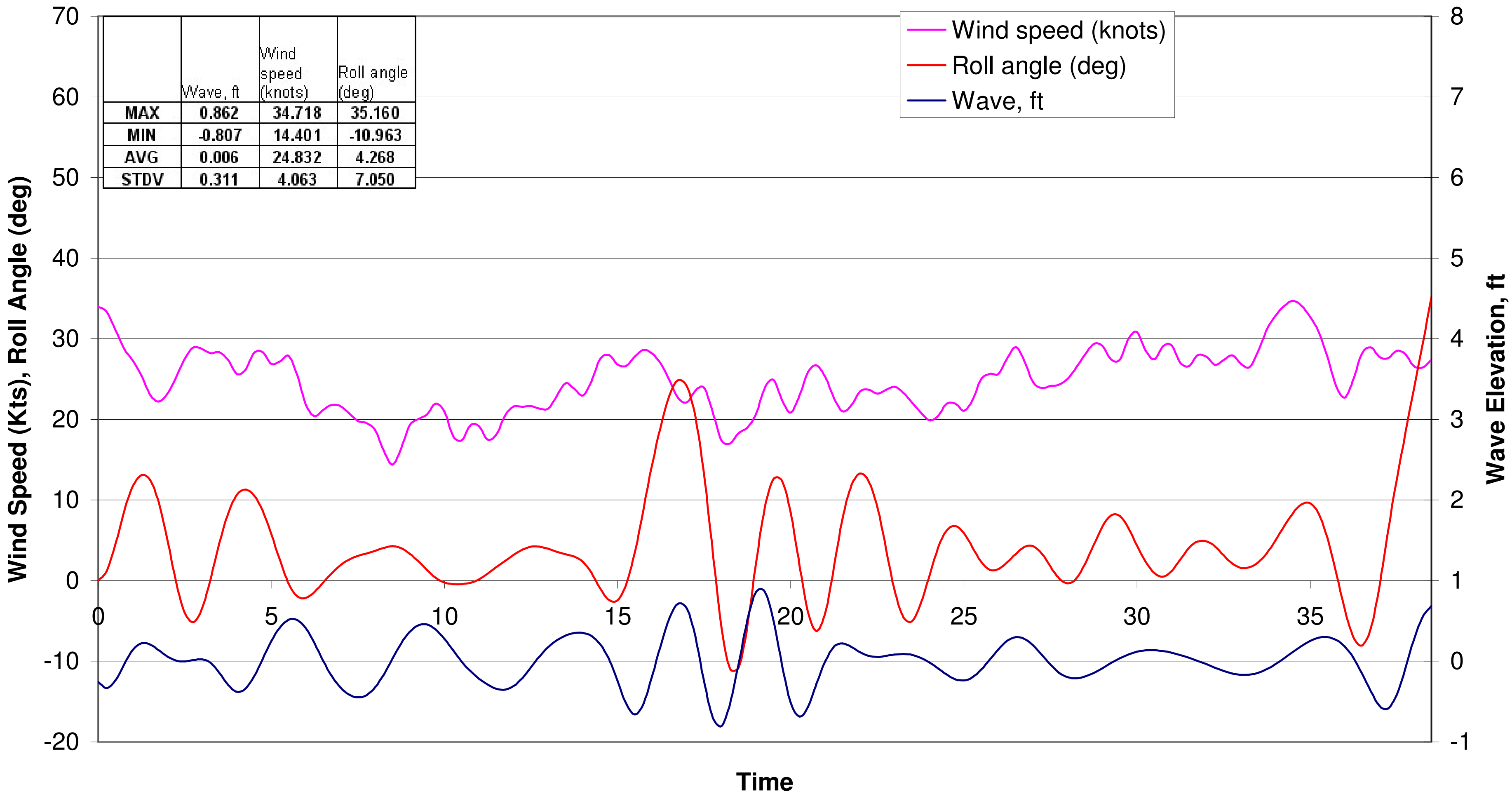
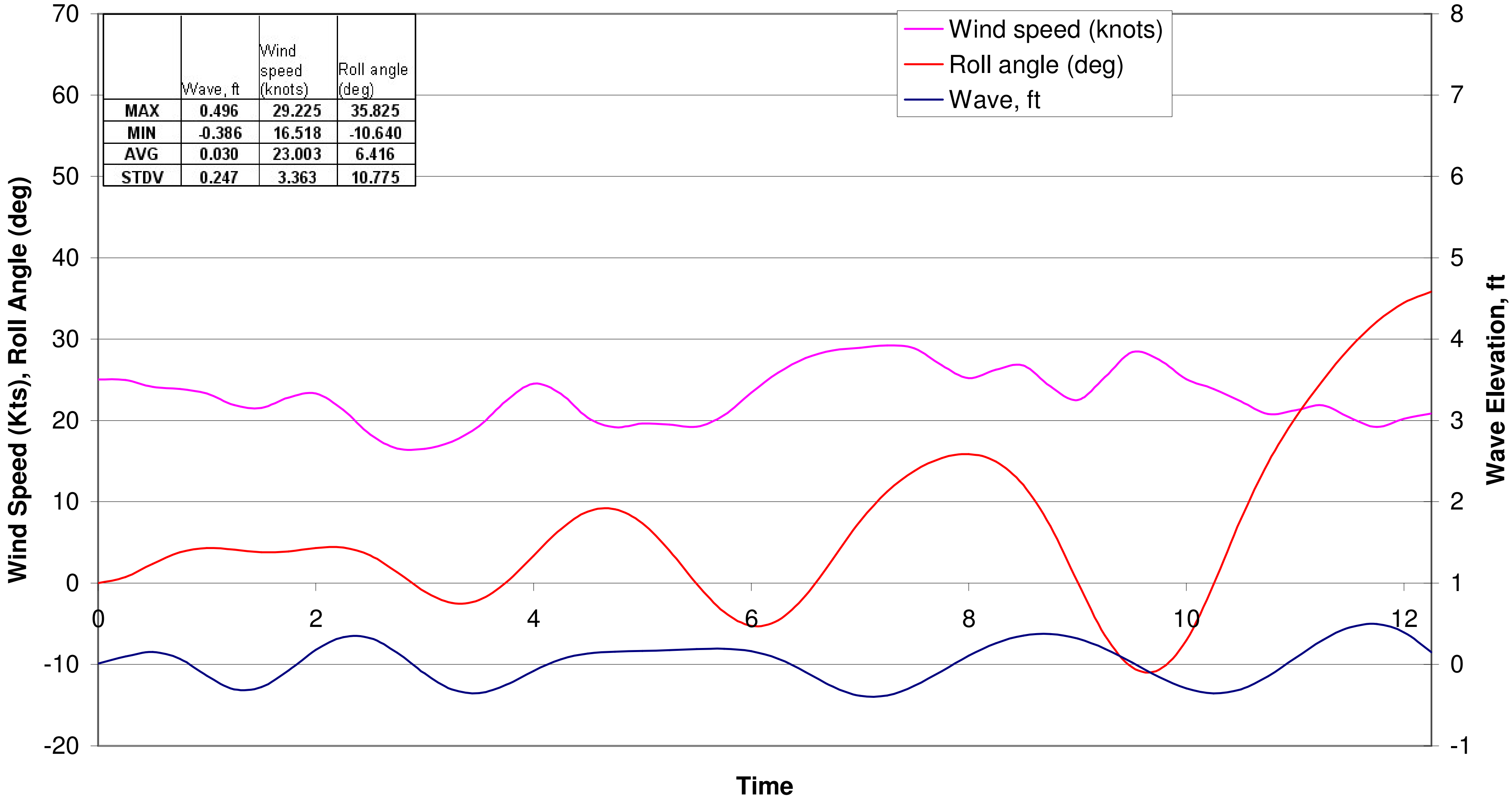
CASE #12



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.862	34.718	35.160
MIN	-0.807	14.401	-10.963
AVG	0.006	24.832	4.268
STDV	0.311	4.063	7.050

CASE #13



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.496	29.225	35.825
MIN	-0.386	16.518	-10.640
AVG	0.030	23.003	6.416
STDV	0.247	3.363	10.775

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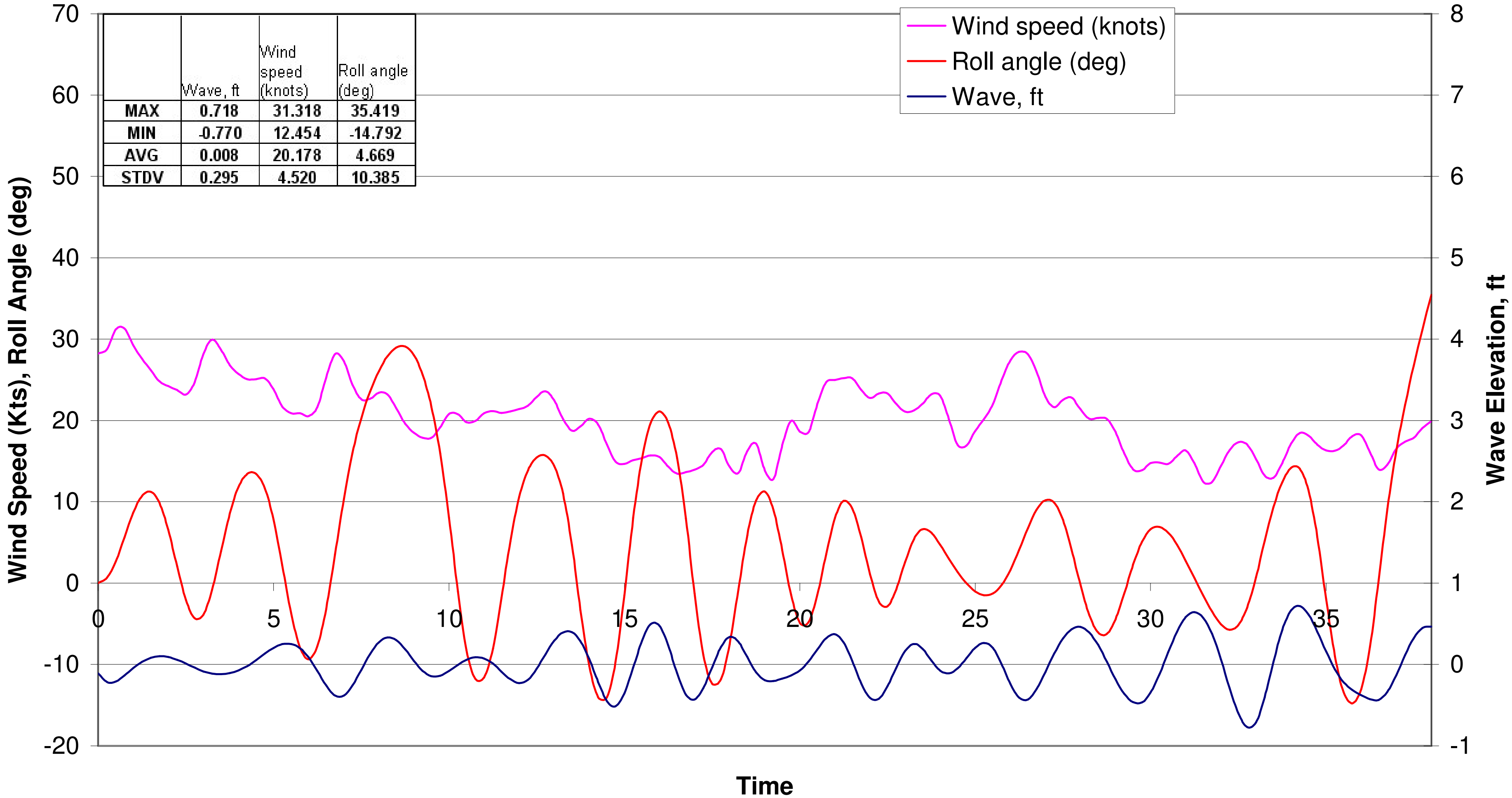
CASE #14



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.718	31.318	35.419
MIN	-0.770	12.454	-14.792
AVG	0.008	20.178	4.669
STDV	0.295	4.520	10.385

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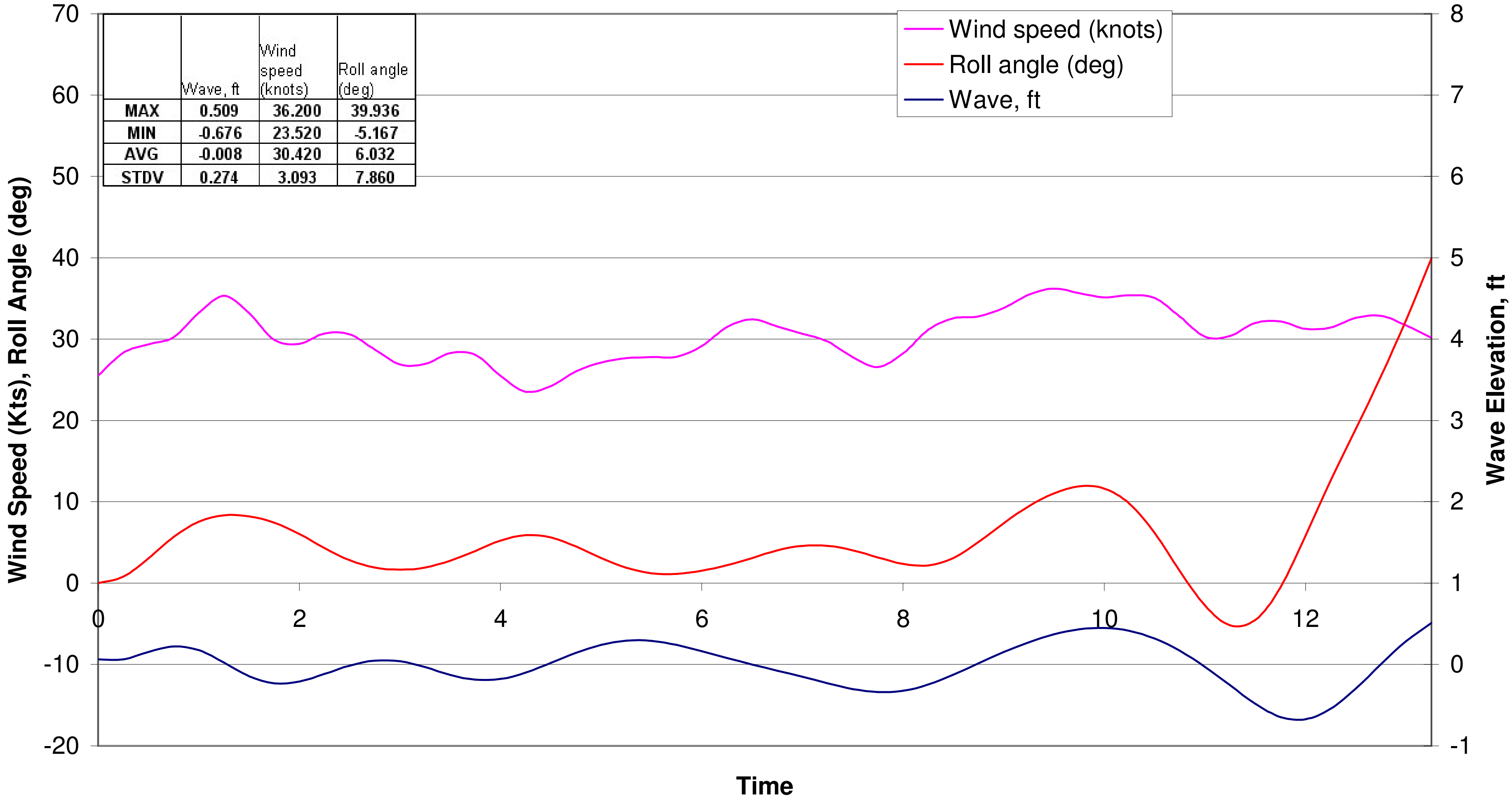
CASE #15

	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.509	36.200	39.936
MIN	-0.676	23.520	-5.167
AVG	-0.008	30.420	6.032
STDV	0.274	3.093	7.860



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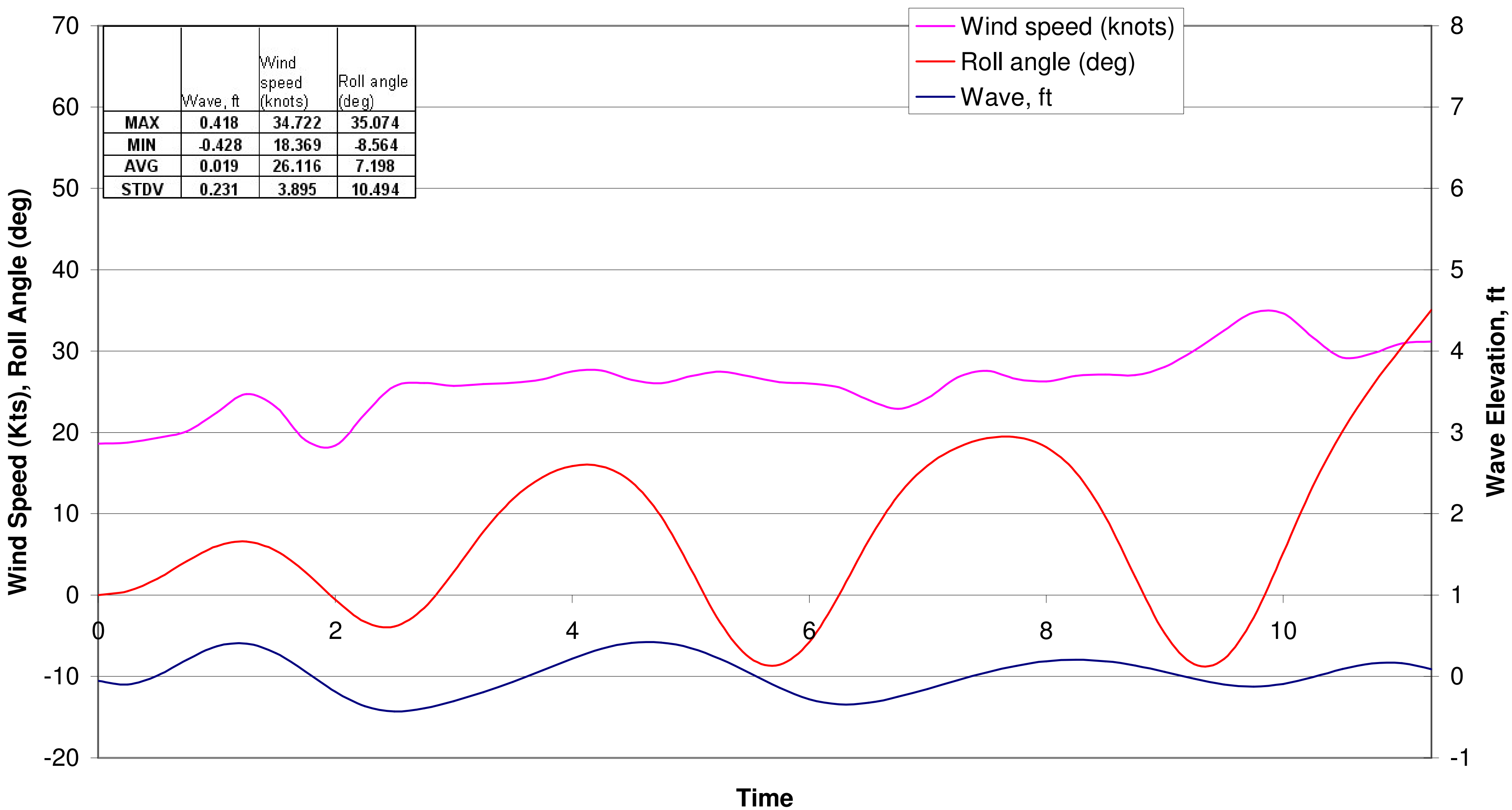
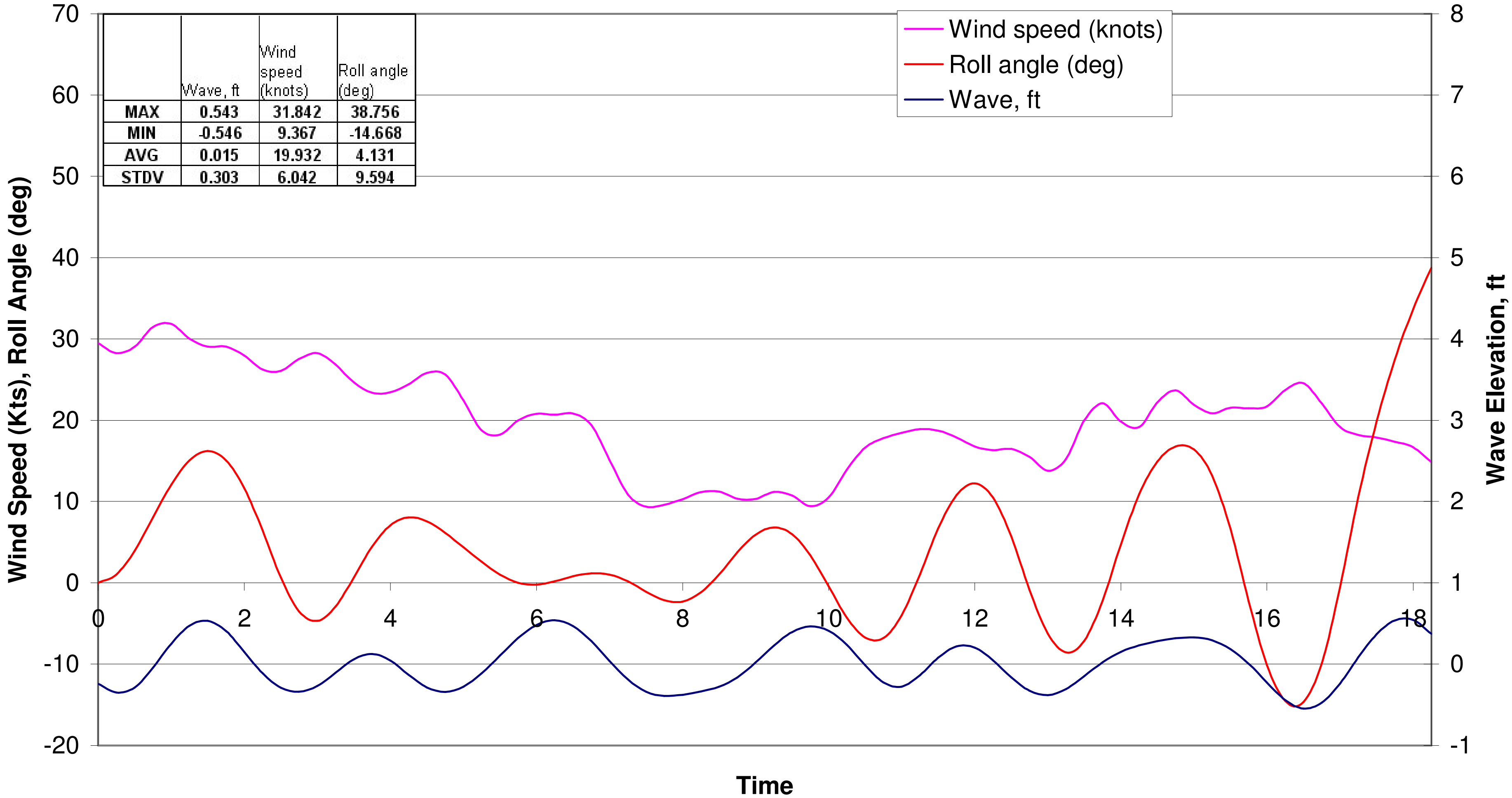
CASE #16



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.418	34.722	35.074
MIN	-0.428	18.369	-8.564
AVG	0.019	26.116	7.198
STDV	0.231	3.895	10.494

CASE #17


	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.543	31.842	38.756
MIN	-0.546	9.367	-14.668
AVG	0.015	19.932	4.131
STDV	0.303	6.042	9.594

Wind speed (knots)
Roll angle (deg)
Wave, ft
Wind Speed (Kts), Roll Angle (deg)
Wave Elevation, ft
Time
70
60
50
40
30
20
10
0
-10
-20
8
7
6
5
4
3
2
1
0
-1
0
2
4
6
8
10
12
14
16
18

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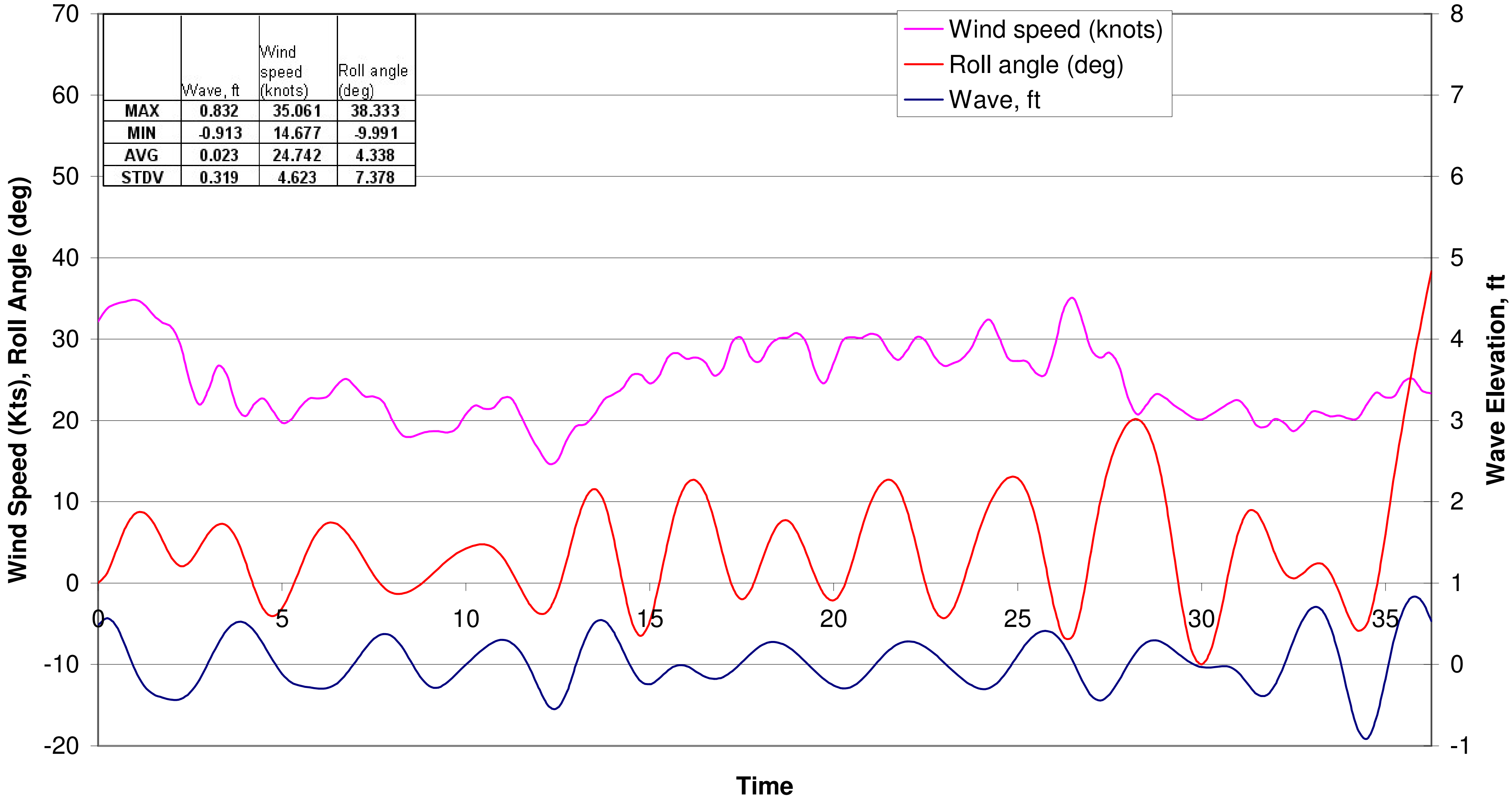
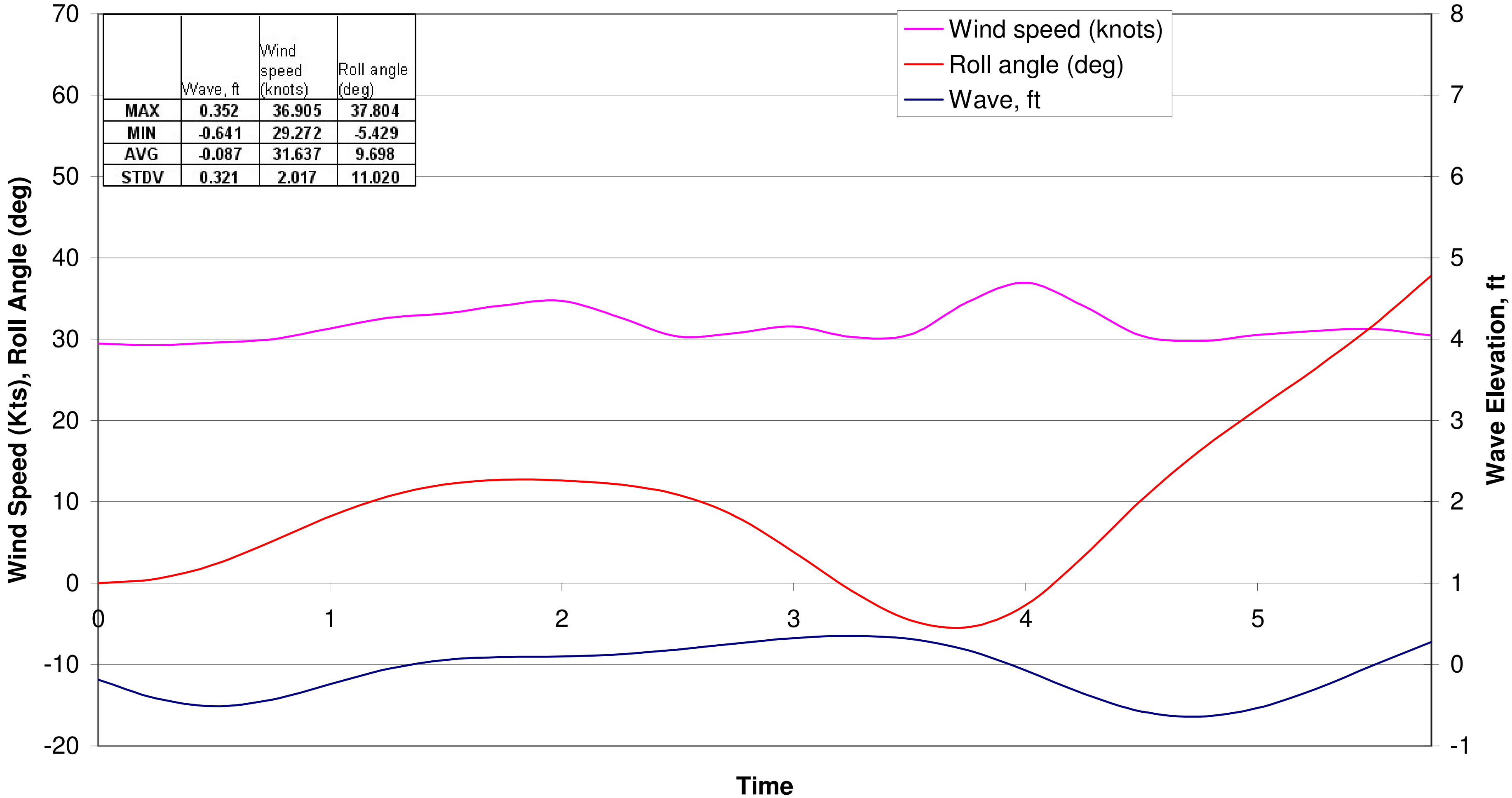
CASE #18

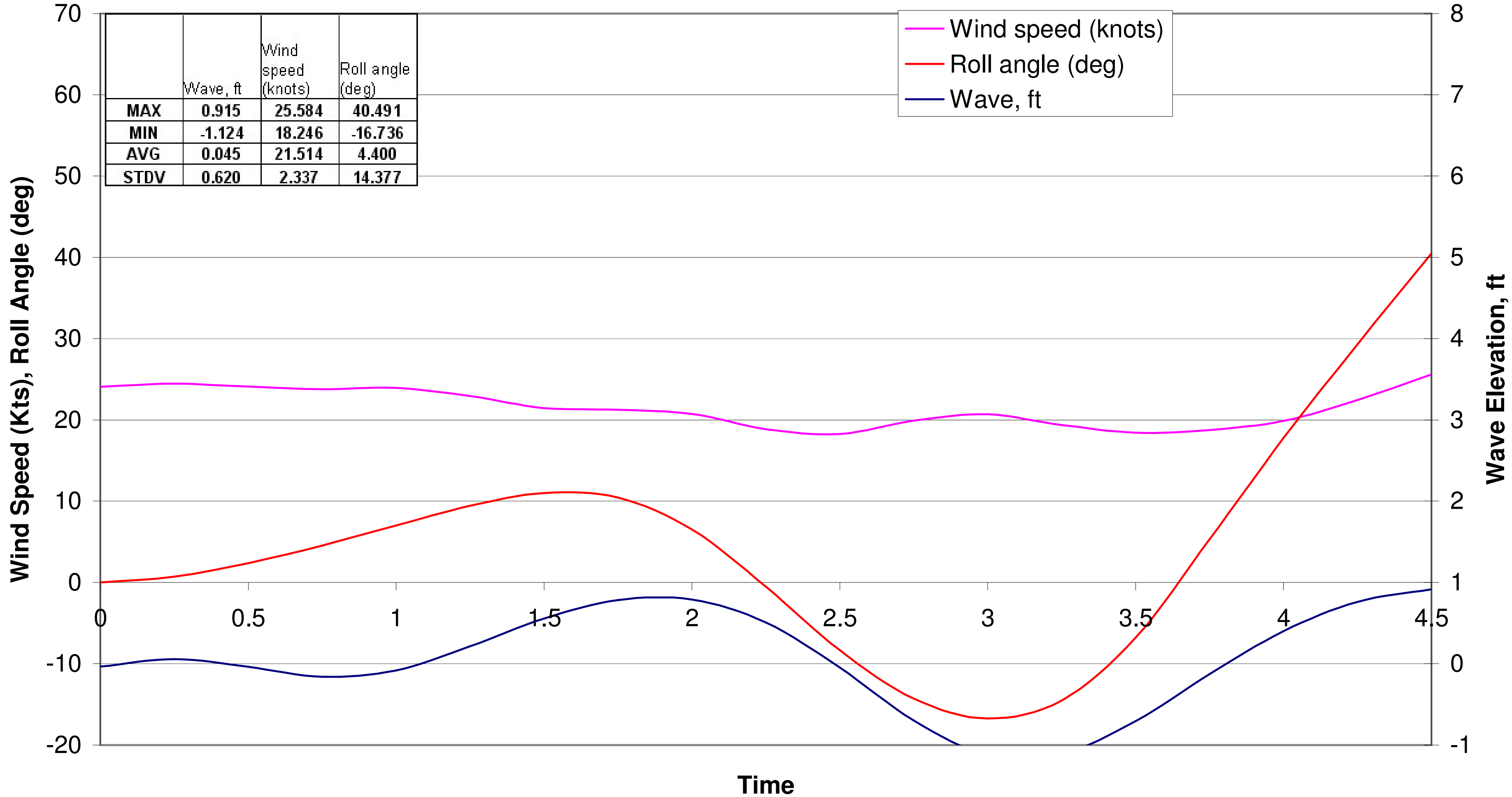


CASE #19



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.352	36.905	37.804
MIN	-0.641	29.272	-5.429
AVG	-0.087	31.637	9.698
STDV	0.321	2.017	11.020

CASE #20



	Wave, ft	Wind speed (knots)	Roll angle (deg)
MAX	0.915	25.584	40.491
MIN	-1.124	18.246	-16.736
AVG	0.045	21.514	4.400
STDV	0.620	2.337	14.377

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APPENDIX F
Simulation Data Time Series and Plots

See CD-ROM “Report on the Capsize of the Passenger Vessel Lady D” for Electronic Files

The visualization can be viewed from the CD file folder labeled "Appendix F – Visualization."

Engineering simulations were performed using AQWA software from Century Dynamics. These produced numerical engineering solutions. AQWA has 3D visualization capability that is adequate for viewing engineering solutions. To improve the visual resolution and clarify the sequence of events, a detailed 3D visualization has been developed using industry standard graphics, animation and movie production software.

The visualization shows LADY D running at 5 knots with wind and waves and then initiates a turn to port. When LADY D is port to wind and waves, it capsizes to starboard. Rain is not shown in the visualization. The sequence of events shown is:

- Travel with wind and waves for 15 seconds. Pitch, heave and roll motions are small.
- Initiate a turn to port. The turn follows a circular arc of 1.35 ship lengths radius (48') and will take 9 seconds to turn port beam to wind and waves. This is a 90° heading change at 10° per second.
- Shortly after initiating the turn, LADY D rolls approximately 10° to starboard and recovers.
- Towards the conclusion of the turn, LADY D again rolls approximately 10° to starboard and recovers.
- At 25 seconds, LADY D experiences an unrecoverable roll to starboard and capsizes.

The motions of LADY D were generated within the AQWA simulations and imported to the visualization. An AQWA simulation generated data for the initial 15 seconds, when LADY D is running with wind and waves. The last 10 seconds, show the final 3 roll oscillations from simulation case #2. During simulation case #2, the significant wave height was 1.18 feet, the average wind speed was 25.3 knots and the maximum gust was 36.4 knots. The conditions and sequence of events is consistent with those presented in the main body of the report.